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Technical Report

No. 13499

M1A1 DRIVER's SEAT ASSEMBLY

CONTRACT DAAE07-89-C-R041

DECEMBER 1990

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THIS REPORT DOCUMENTS A PROGRAM TO DEVELOP AND FABRICATE A COMPOSITE MATERIAL DRIVER'S SEAT FOR THE M1A1 TANK. THE DRIVER'S SEAT INCORPORATES COMPOSITE MATERIALS TO REDUCE WEIGHT WHEN COMPARED TO THE ALUMINUM COUNTERPART.

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1.0. INTRODUCTION

The original design weight for the M1 tank was 58 tons. Additional capabilities, such as improvements introduced in the Block I Program, have led to significant weight growth of the vehicle. The current M1A1 vehicle being manufactured by GDLS weighs 65 tons. Planned improvements in survivability, track, and Block II will lead to a 70-ton vehicle if weight growth is not offset by weight reduction in the base vehicle platform. A 70-ton tank will lead to severe transportability problems and may impact some key automotive performance parameters.

GDLS recognizes the importance of weight reduction for the M1 family of vehicles and is committed to achievement of this goal. The composite material driver's seat offers an excellent opportunity to reduce the fundamental structural weight of the M1 vehicle chassis.

The procurement cost of the current aluminum seat is high due to material and processing costs. The high processing costs are attributed to the amount of welding required. Composites technology offers a unique opportunity to reduce the procurement cost of the seat assembly and thereby earn a position on the M1A1 vehicle.

2.0. OBJECTIVE

The two major objectives for the M1A1 composite driver's seat program were:

- Design a composite driver's seat assembly which would meet all the requirements of the current metallic seat assembly, be interchangeable with the current assembly, and have a maximum weight of 90 pounds.

- Develop a cost effective, reliable production process for the M1A1 driver's seat assembly which will reduce the manufacturing cost to $850 at production volumes of 700 per year.

3.0. APPROACH

This report, prepared by General Dynamics, Land Systems Division (GDLS), for the U.S. Army Tank-Automotive Command under Contract DAAE07-89-C-R041, describes the process used for developing and fabricating three driver's seats, lighter and less expensive than the current M1A1 seats. The weight and cost savings were achieved by using organic composite materials to replace three of the current seat components (the seat frame, seat back, and access cover) and by redesigning two existing metal components (the left and right seat brackets). The end result is a seat assembly which is nearly 20% lighter than the current design and is more economical to produce.

4.0. CONCLUSION

Weight reduction in the M1A1 Abrams tank (and future M1A2) continues to be a highly desirable goal. The composite driver's seat reduces weight when compared to the current seat assembly, while reducing production and life cycle costs. The composite version is completely interchangeable with the current seat assembly, using the same mounting hardware and attachments. The composite seat assembly also satisfies the structural and material requirements.

5.0. RECOMMENDATIONS

While epoxy tooling is sufficient for prototype applications, production molds should be made of steel to ensure that tooling degradation does not occur from fabricating large numbers of parts. In addition, the epoxy tooling was not fitted with any type of heating lines. Production tooling for the composite parts should be designed with some means providing internal heat to the mold. This will not only help speed the molding process, it will also provide greater control over the curing cycle of the parts.

In an effort to minimize tooling costs, the molds used to fabricate seat back and the access cover were designed to utilize the squeeze molding process. In production, however, it would be cost effective if these molds were designed to use the resin transfer molding (RTM) process. To further minimize production costs, the access cover mold should be designed such that two parts are produced with each molding cycle. A simple cutting operation is all that would then be required to finish the parts.

It is also recommended that a six cavity, multi-injection point resin transfer mold be built to fabricate the pre-cured inserts used in the seat frame rails. The inserts for this program were produced by molding a large panel and then hydrodynamically cutting the inserts from the panel. However, given production volumes, this process is less cost efficient than a straight resin transfer molding operation.

Because the cross-sectional thickness of the composite seat components is greater in most areas than their metallic counterparts, alternate fasteners and modifications to existing components were required to assemble the parts. See Section 3.6 Final Assembly for additional details.

Before placing the composite seat in production, the assembly should be completely tested in the M1A1 tank. Level III drawings of the modified components should be completed. Planning should be initiated to incorporate the composite driver's seat into the M1A2 scheduled for implementation in 1992.

6.0. REQUIREMENTS

The following are the mechanical/physical requirements and the process requirements outlined by the contract for the composite drivers' seats:

Mechanical/Physical Requirements:

- fit within the existing space claim
- capable of withstanding the required shock loadings
- capable of withstanding required static loads
- provide the same "form, fit and function" as the current seat
- match the stiffness of the current seat
- endure temperature extremes of $-25^{o}F$ to $+200^{o}F$
- materials chosen must be self-extinguishing

Process Requirements:

- processes chosen must be capable of producing three prototype drivers' seats.
- processes must meet cost and reliability requirements for annual production rates of 500-1000 units
- unit cost target of $850 at annual production rates

7.0. ENGINEERING DESIGN

7.1. Design Approach

GDLS selected five components of the current M1A1 tank driver's seat for redesign. These were the following:

- Driver's Seat Bracket-Left (P/N 12287570)
- Driver's Seat Bracket-Right (P/N 12287571)
- Upper Backrest (P/N 12287593)
- Driver's Seat Frame (P/N 12287601-3)
- Access Cover for the Seat Torsion Bars (P/N 12287651)

These components comprise the majority of the structural weight and cost of the current seat assembly. Figures 7-1 through 7-4 illustrate the major components of the seat assembly. Table 7-1 shows the weight breakdown of the major seat components. These weights were determined by disassembling and weighing an actual seat assembly.

The redesigned components are interchangeable with the current hardware on the component level. Therefore, not only is the seat assembly interchangeable but also the individual components. This approach is both low cost and low risk. Redesigning the entire seat assembly would have resulted in a program of greater technical risk and cost.

The current M1A1 driver's seat has been recognized for its outstanding Human Factors Engineering (HFE). The GDLS approach for the new composite material seat has retained all the same functional characteristics of the current metallic seat. The form, fit, and function are identical to the current seat. Specifically, the cushions and adjust mechanisms remain unchanged.

The current aluminum seat frame and seat back have been replaced by composite material components containing a sandwich laminate construction. The current steel access cover (covers the seat torsion rod assembly and adjustment hardware) has been replaced by a solid composite cover which is simplified in design. The material of the high-strength steel seat mounting brackets remain unchanged, but the brackets have been optimized for weight within the current envelope of the forged parts.

The metallic adjustment hardware remains unchanged. Certain thicknesses at attachment points were left unchanged so as not to cause problems with existing fasteners, some of which are designed specifically for this application.

The GDLS design detailed in this proposal reduces weight by 18.4 pounds when compared to the current seat assembly. The measured seat assembly weight of 84 pounds is well under the TACOM requirement of 90 pounds. Materials and processes have been chosen which will minimize production fabrication costs.

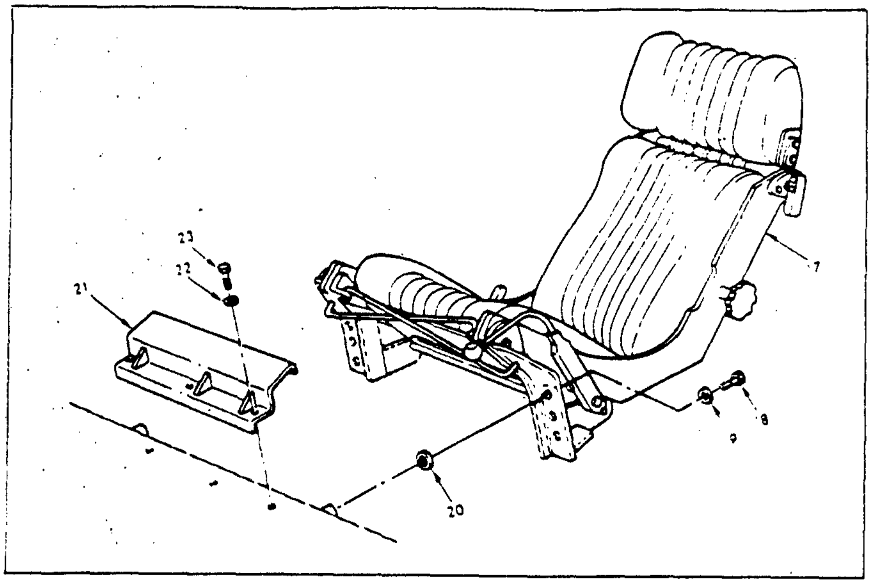


Figure 7-1. Driver's Seat Assembly and Related Parts

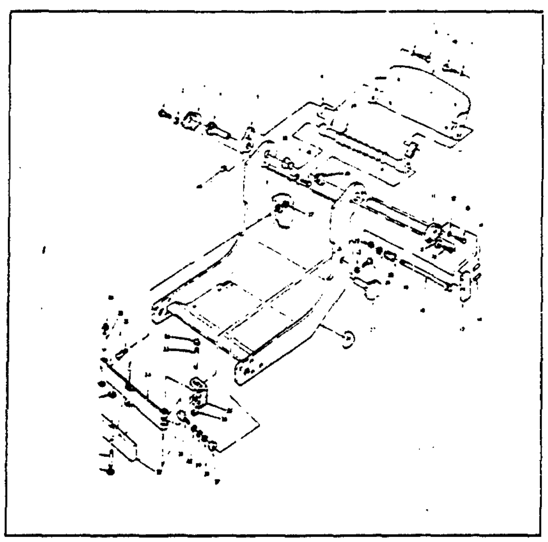


Figure 7-2. Driver's Seat Assembly Components

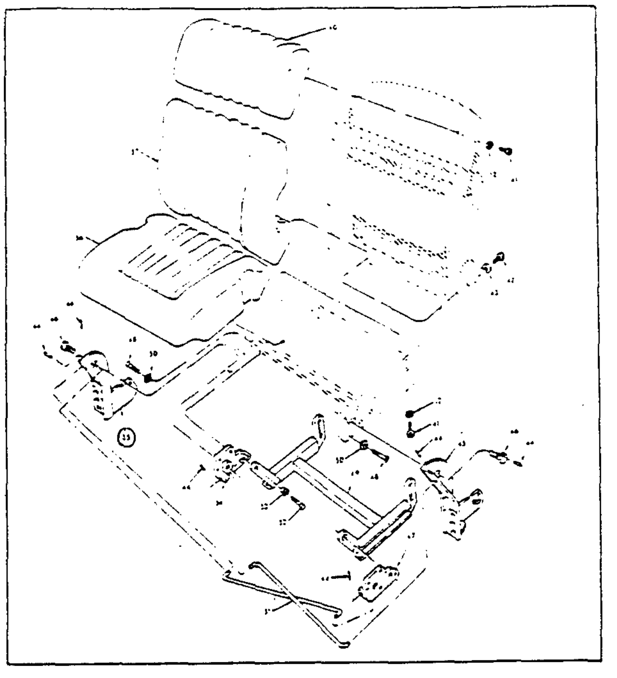


Figure 7-3. Driver's Seat Assembly Components

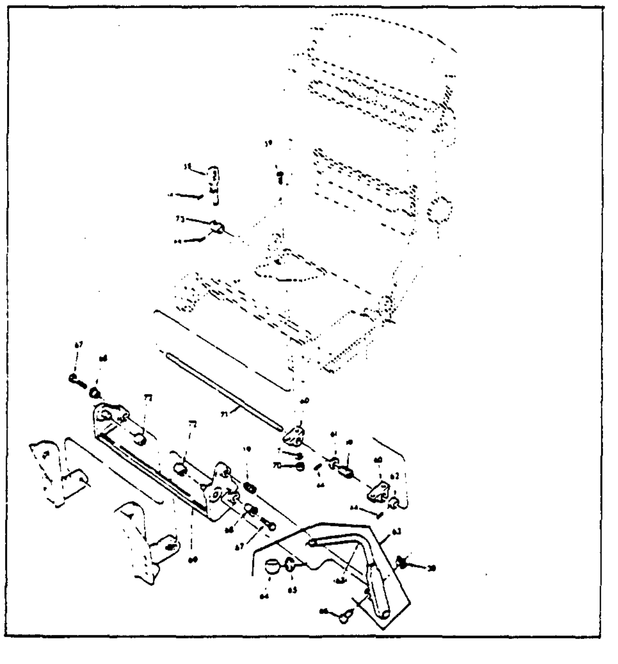


Figure 7-4. Driver's Seat Assembly Components

Table 7-1. Weight of Major Components of Seat Assembly

COMPONENT	PART NUMBER	ILLUSTRATION NUMBER	WEIGHT
Seat Frame	12287601	24	18.5
Seat Back	12287593	9	4.9
Seat Bracket - Left	12287570	45	13.2
Seat Bracket - Right	12287571	55	9.7
Access Cover	12287651	21	4.6
Seat Cushions	12312151 12312155 12312157	57 40 56	19.7
Pivot Brackets	12312157-1-2	47	2.6
Connecting Ling	12287596	69	7.4
Torsional, Spiral Spring	12287649	51	0.9
Manual Control Lever	12287640	63	4.5
Seat Subframe	12287612	49	6.0
Tube Assy and Attachments	12287588	11	3.7
Back Support	12287608	6	3.0
Knob	12287583	23	0.9
Assorted Hardware	Various	Various	2.8
TOTAL WEIGHT			102.4

7.2. Design Criteria

The composite driver's seat structural design requirements are as follows:

- The composite seat design must have the same form, fit, and function as the current seat. (Contract Ref. C.3.1, Page 4)

- The operating temperature shall be -25°F to +140°F with storage temperatures to 200°F. (Contract Ref. C.3.2.1, Page 4)

- The weight of the entire driver's seat must not exceed 90 pounds. (Contract Ref. C.3.3.2.2, Page 4)

- The seat cushions used on the production aluminum seat must be retained. (Contract Ref. C.3.2.5, Page 5)

- The composite seat must be interchangeable with the current aluminum design. (Contract Ref. C.3.2.6, Page 5)

- Loads induced by the adjustment mechanism must produce no localized degradation. (Contract Ref. C3.2.9, Page 5)

The GDLS design of the composite driver's seat assembly detailed in this report meets all of these requirements.

Review of all existing part drawings, including the installation accommodation drawing (No. 1228610), provided the necessary information to meet form, fit, and interchangeability requirements. Static stress analysis and shock testing assured that function was preserved while exceeding the weight reduction requirements.

The materials selected exhibit little degradation of properties within the specified temperature range. In addition to the contract criteria, GDLS imposed a requirement that all composite materials be self-extinquishing.

Loads used in the structural analysis are provided in Table 7-2. A factor of safety of 1.5 was applied to the static equivalent accelerations shown. A 1g driver weight of 323 lbs. was assumed as the worst case condition. This results in a conservative condition as it represents a 95th percentile male with 90 lbs. of gear. The equipment static accelerations and high intensity shock values are the result of instrumented mine blast testing in an M1 hull.

Table 7-2. Static Accelerations and Shock Loads

- BASIC SHOCK 30 G AT 11 ms

HIGH INTENSITY SHOCK

Location	Frequency Response	Peak Acceleration (g's)
Driver Seat	100-1000 Hz	Over 1000 Hz
Vertical	1000 g's	4000 g's
Long.	1000 g's	4000 g's
Trans.	1000 g's	4000 g's

EQUIVALENT STATIC ACCELERATION

Location	Accel (1kHz)		(200 Hz)		Vel (1kHz)	
	Plus	Minus	Plus	Minus	Plus	Minus
Driver Head,						
Vert.	9	8	8	7	8	5
Long.	4	4	3	4	1	4
Trans.	4	3	4	3	1	0
Driver Chest						
Vert.	4	6	4	6	2	4
Long.	6	6	5	5	7	1
Trans.	2	2	2	2	1	1
Driver Pelvis,						
Vert.	1	7	1	7	0	5
Long.	11	2	10	2	4	0
Trans.	5	5	5	4	1	1

7.3. Structural Design

This section provides the basic information regarding internal construction and a stress analysis of the critical detail for each component. A Level II drawing for each component was prepared under this contract and should be referred to for particular areas of interest. Margins of safety are summarized in Table 7-3.

Table 7-3. Margin of Safety Summary

COMPONENT	PART NO.	LOADING CONDITION	CRITICAL MODE	MARGIN OF SAFETY
RT. MTG.BRACKET	12287571-X	5G LATERAL	BENDING	+ 0.60
LT. MTG. BRACKET	12287570-X	9G VERTICAL	TENSION (LUG TEAROUT)	+ 3.50
TORSION ROD COVER	12287651-X	1G HANDLING	BENDING	+ 0.23
UPPER BACK REST	12287593-X	9G VERTICAL	BEARING	+0.32
FRAME	12287601-X	VERTICAL	STIFFNESS	- 0.005

FACTOR OF SAFETY = 1.5

7.3.1. Seat Mounting Brackets. The current seat mounting brackets (P/N 12287570 and P/N 12287571) are 4130 or 4140, Class D, steel forgings conforming to MIL-S-46172. The right and left seat brackets were analyzed separately using both finite element and conventional methods for the purposes of establishing existing margins of safety and identifying areas of low stress where material could be removed. The NISA finite element model was particularly helpful in identifying stress concentrations. This can be seen in Figure 7-5 which shows the modified right bracket stress contours. The highly stressed areas were avoided in the machining of excess material. Conventional methods reinforced the NISA results which indicated low stresses in most other areas.

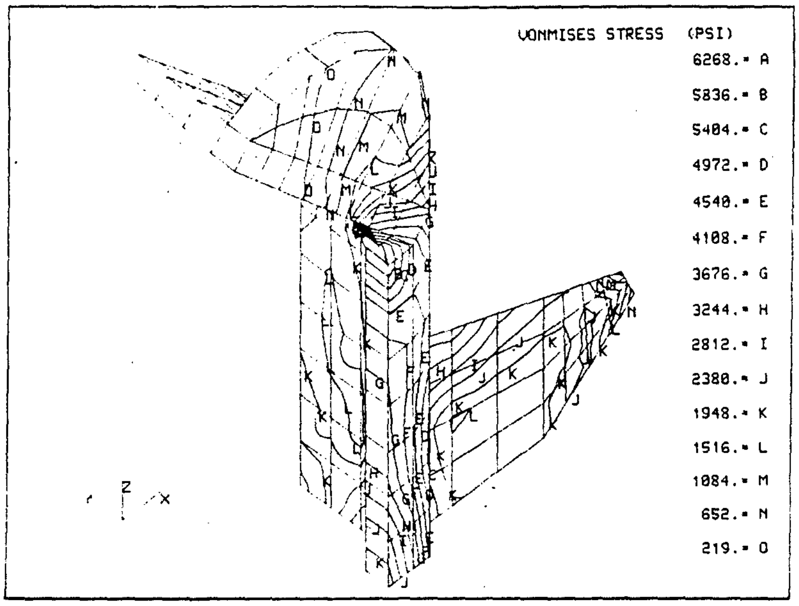
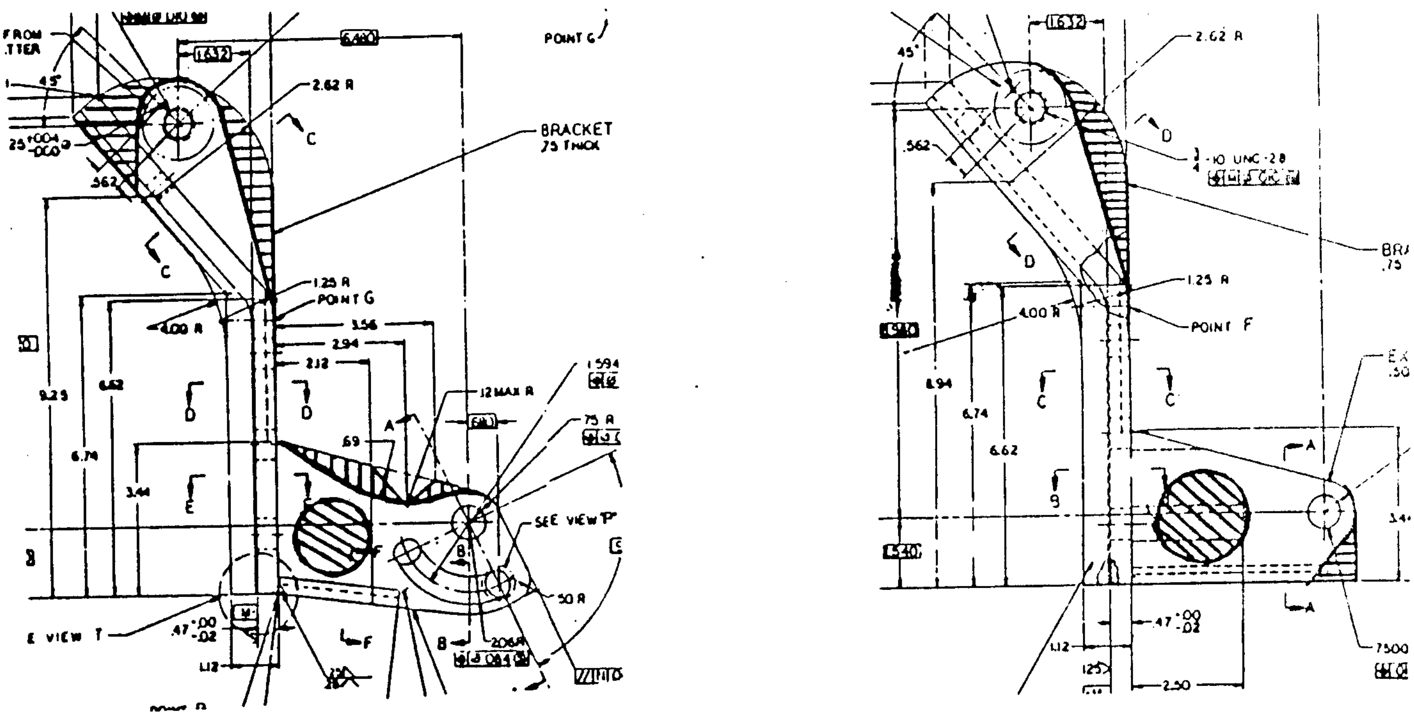


Figure 7-5. Stresses in Modified Right Side Bracket

The weight reduction goal for redesigned brackets was 30 percent. Machining of low-stressed material resulted in an actual measured weight reduction of 32 percent or 7.25 lbs. for the pair. The areas which were removed are exemplified in Figure 7-6. Weight savings could reach 40% if attachment hardware was changed to compensate for reduced thicknesses in certain areas. Stress analysis of critical areas for the remachined brackets are presented in Figures 7-7 and 7-8.

AREAS REMOVED



LEFT RIGHT

Figure 7-6. Material Removed in Seat Brackets

COMPONENT: RIGHT SEAT BRACKET

TEMPERATURE: ROOM TEMPERATURE

MATERIAL: 4130 STEEL FORGING MIL-S-46172
PER DRAWING # 12287571

FREE BODY DIAGRAM:

VALUES INCLUDE 1.5 FACTOR OF SAFETY

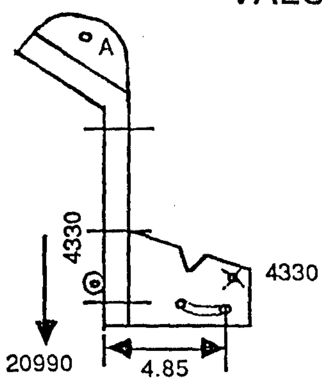
5 G SIDE LOADING
100% ASSUMED ACTING ON
LOWER LUG

MAX. BOLT LOADS

$$\text{TENSION} = \frac{21}{.75} = 28\text{k}$$

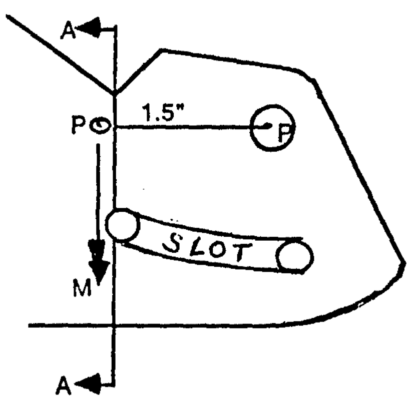
SHEAR = 4.3 k

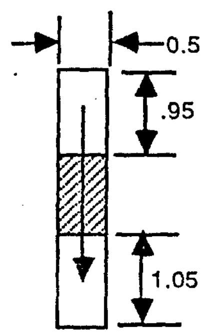
o.k.



UNITS ARE POUNDS & INCHES

STRESS ANALYSIS:





SEC A-A

$$M = 4330 \times 1.5 = 6490 \text{ in lb}$$

$$I = \frac{2 \times .5^3}{12} = .0208 \text{ in}^4$$

$$f_b = \frac{M\,C}{I} = \frac{6490 \times .25}{.0208}$$

$$f_b = 78 \text{ ksi}$$

$$F_{tu} = 125 \text{ ksi}$$

Per Mil-H-5D

$$\text{MARGIN OF SAFETY} = \frac{125}{78} - 1 = \underline{\underline{+ .60}}$$

Figure 7-7. Right Seat Bracket Stress Analysis Summary

COMPONENT: LEFT SEAT BRACKET

TEMPERATURE: ROOM TEMPERATURE

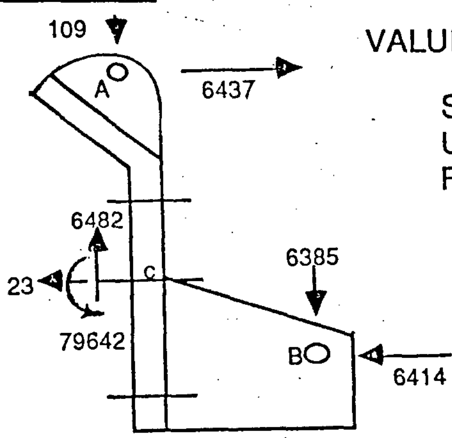
MATERIAL: 4130 STEEL FORGING Mil - S- 46172
Per Drwg. # 12287570

FREE BODY DIAGRAM:

MAX BOLT LOADS

Ten.= $\frac{79642}{4}$ =19.9k ok

Shear= $\frac{6482}{3}$ =2.2k ok



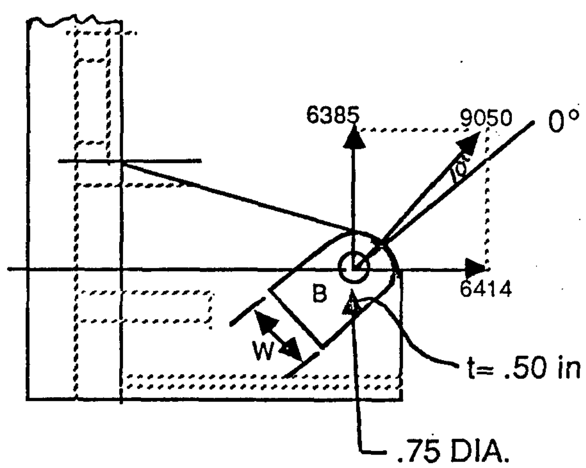
VALUES INCLUDE 1.5 FACTOR OF SAFETY

SEAT RECLINED , 15 G VERTICAL
ULTIMATE LOADS(100% REVERSIBLE)
PER NISA RUN AL23OUT

V
H

UNITS ARE Lbs. and Inches

LUG CHECK:



ANALYSIS PER BOEING 86B1 , 7.1.1

P= 9050 Lb
e = .75 in
W = 1.5 in
D = .75 in
Θ = 10° OBLIQUITY

$P_{ALLOWABLE} = K_t \times k_{\theta} \times F_{tu} \times D \times t$

K_t = .93 Per Fig. 7.1.1-2

K_{θ} = .95 Per Fig. 7.1.1-4

F_{tu} = 125ksi Per MIL-H 5D

$P_{ALLOWABLE}$ = .93 x .95 x 125000 x .75 x .5 = 41000 Lb

MARGIN OF SAFETY = $\frac{41}{9.05}$ - l = $\underline{\underline{+3.5}}$

Figure 7-8. Left Seat Bracket Stress Analysis Summary

7.3.2. Access Cover. The access cover is not an integral part of the driver's seat assembly, as it is mounted separately to the hull floor. It covers the seat torsion rods and provides a smooth surface for contact with the driver's legs. The only structural requirement on this part is that it not break when being stood on or jumped on by the driver.

The design of both the current and composite access cover is shown in Figure 7-9. The existing steel part is a gusseted weldment which weighs 4.6 lbs. The weight target for laminated composite part was 1.5 lbs. Measurement of finished parts resulted in an actual weight of .8 lbs.

Stress analysis showed adequate strength for the composite cover, although there is considerably more vertical deflection when compared to the metal part. Increasing bending stiffness by using gussets would result in an unjustified increase in cost and complexity. If increased bending stiffness would be required, the torsion rods could be wrapped with an elastomeric bushing. Stress analysis predicts the access cover to be bending critical. The summary of the stress analysis is given in Figure 7-10.

7.3.3. Upper Backrest. The upper backrest is attached to the seat frame and supports the driver's upper back and shoulders. The current part is fabricated out of formed aluminum plate with welded attachment flanges. The composite component is of balsa core sandwich construction with solid laminate integrally molded flanges. Figure 7-11 shows both metal and composite pieces and an internal cross section of the composite part construction.

Worst case loading for the upper backrest is the 9g vertical equivalent static acceleration from Table 7-2 with the seat and backrest in the fully reclined position. Stress analysis was performed using a 57 lb. mass (man and equipment) as the 1g load, applied along a horizontal line eight inches from the hingeline. The critical area was an attachment flange fastener.

The stress analysis is shown in Figure 7-12. All margins of safety were positive. Weight reduction on this component was measured at 2.0 lbs. per assembly.

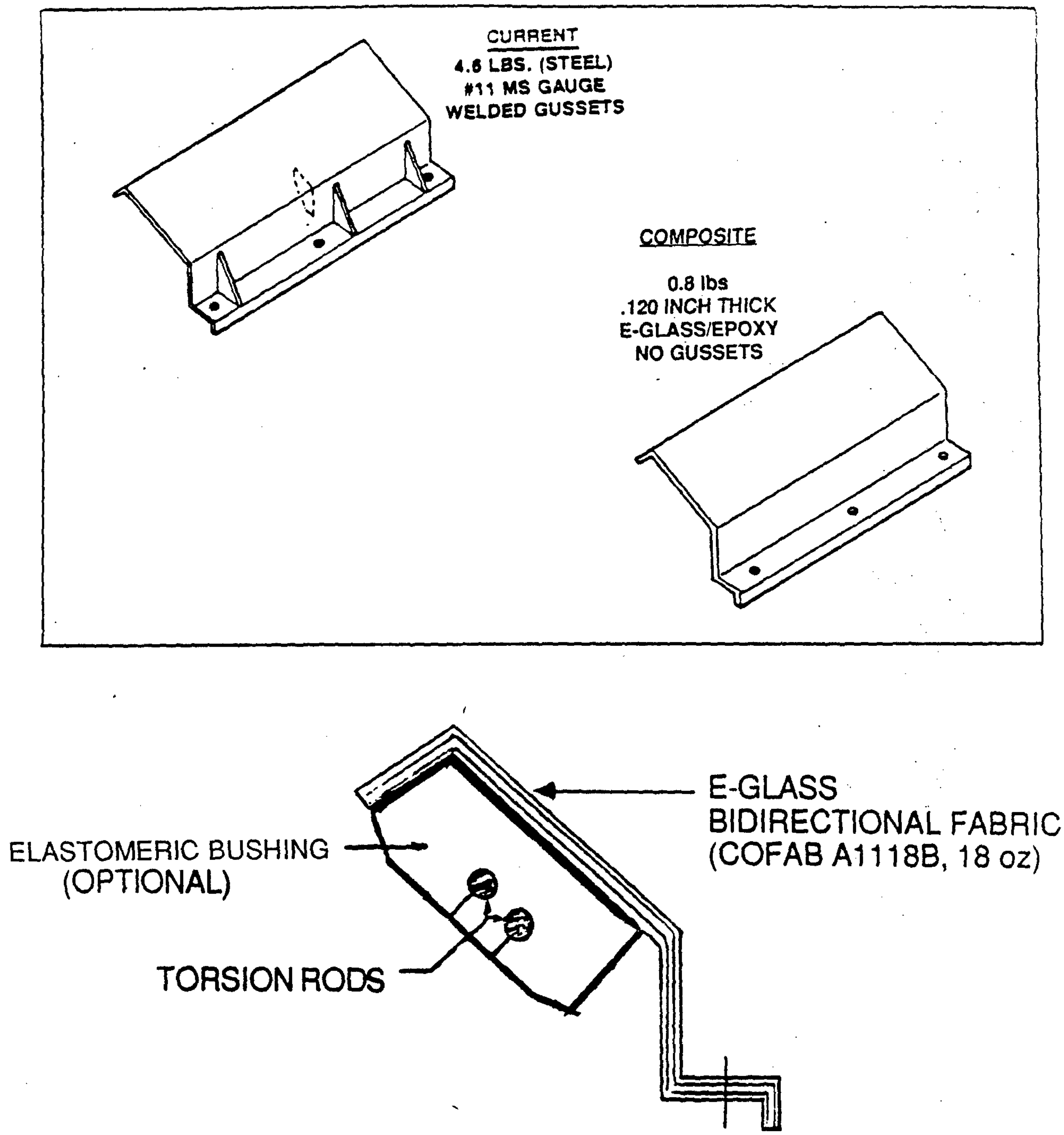


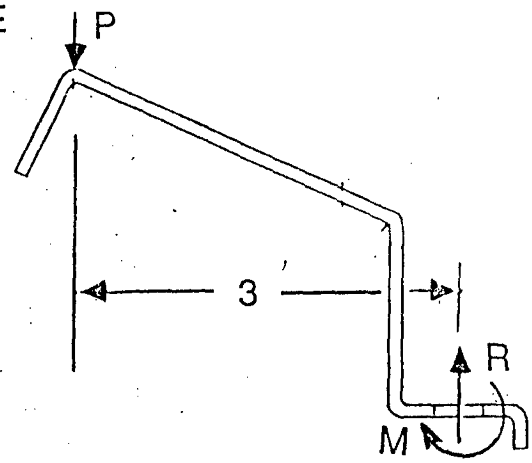
Figure 7-9. Composite and Metallic Access Covers

COMPONENT: TORSION ROD COVER

TEMPERATURE: ROOM TEMPERATURE

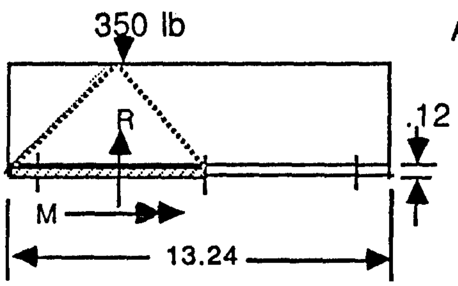
MATERIAL: 0 / 90 COFAB E-GLASS / VINYLESTER
55% FIBER VOLUME

FREE BODY DIAGRAM:



LOAD CONDITION: 1 G HANDLING
P = 233 lb x 1.5 SAFETY FACTOR = 350 lb
M = 350 x 3 = 1050 in-lb

BENDING CHECK:



ASSUME LOAD IS APPLIED OFF CENTER AS SHOWN

R = 350 lb

M = 1050 in-lb

$$f = \frac{6M}{b\,t^2} = \frac{6 \times 1050}{6.62 \times .12^2} = 66 \text{ ksi}$$

LAMINATE ANALYSIS PER COMPCAL (UNIVERSITY OF DELAWARE PROGRAM)

PLY FAILURE STRESSES IN
MATERIAL COORDINATE SYSTEM:

P#	M#	AN	SL(PSI)	ST(PSI)	SLT(PSI)
1	1	0	1.058E+5	4.402E+3	0
2	1	90	-9.090E+2	4.483E+3	0

PLY STRENGTH PARAMETERS (PSI):

LONGITUDINAL TENSILE = 1.629E+5

LONGITUDINAL COMPRESSION= 1.299E+5

PLY FAILURE STRAINS IN
MATERIAL COORDINATE SYSTEM:

P#	M#	AN	L-STR(%)	T-STR(%)	LT-STR(%)
1	1	0	1.739E+0	-1.819E-1	0
2	1	90	-3.758E-2	3.591E-1	0

$$\text{MARGIN OF SAFETY} = \frac{130}{106} - 1 = \underline{\underline{+.23}}$$

Figure 7-10. Stress Analysis for Composite Access Cover

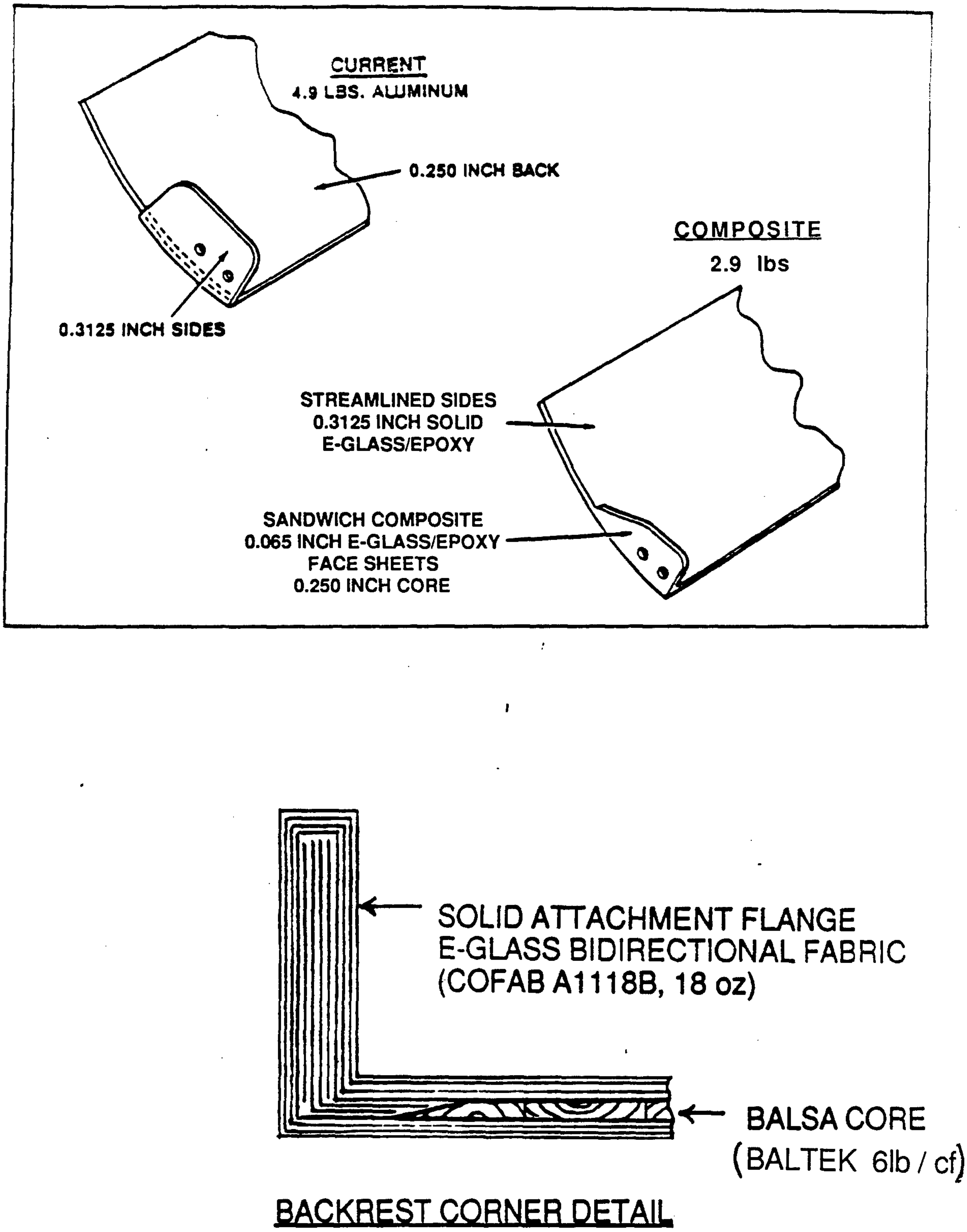


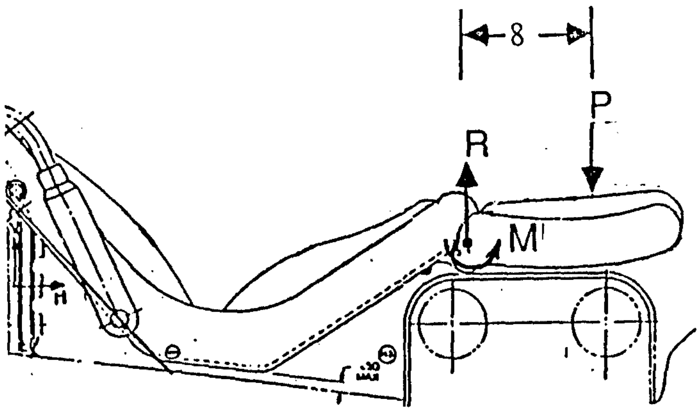
Figure 7-11. Comparison of Composite and Metallic Back Rests

COMPONENT: UPPER BACK REST

TEMPERATURE: ROOM TEMPERATURE

MATERIAL: 0 / 90 COFAB GLASS FABRIC / VINYLESTER 55% FIBER VOLUME

FREE BODY DIAGRAM: LOAD CONDITION : 9G VERTICAL



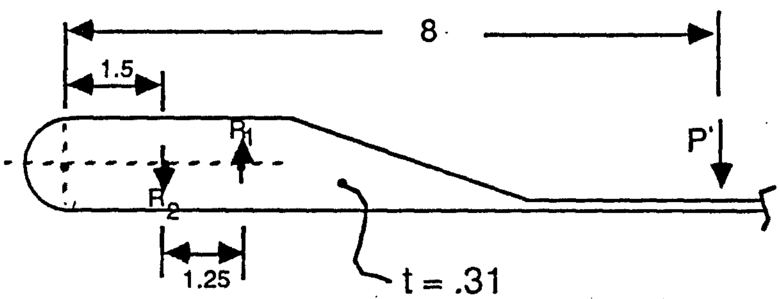
$P = R = 9 \times 57 \times 1.5 = 770$ lbs

$M = 770 \times 8 = 6150$ in lb

AT HINGE LINE

FULLY RECLINED WORST CASE

STRESS ANALYSIS:



ASSUME 60 / 40 SIDE TO SIDE LOAD DISTRIBUTION

$P' = .6 \times 770 = 462$ lbs

$R_1 = 462 \times \frac{8-1.5}{125} = 2400$ lbs

$f_{br} = \frac{R_1}{Dt} = \frac{2400}{.375 \times .31} = 20.7$ ksi

$f_{bru} = 27.4$ ksi (lowest value found for 0/90 layup, 160° F in MIL-H-17A table 4.7)

$$\text{MARGIN OF SAFETY} = \frac{27.4}{20.7} - 1 = \underline{\underline{+\ .32}}$$

Figure 7-12. Stress Analysis for Composite Back Rest

7.3.4. Seat Frame. The seat frame is the major loading carrying structure in the seat assembly. It structurally supports the driver and isolates him from loading as the vehicle undergoes various conditions. The metallic and composite seat frames are illustrated in Figure 7-13.

The current metallic seat is made from a formed 0.250 inch thick aluminum back which is welded to 0.3125 inch thick sides. A moderate strength aluminum alloy, 5454 H32, is the specified material. This alloy has a yield strength of 26,000 psi and an ultimate strength of 36,000 psi with 12% ultimate elongation. Various holes are cut into the frame for headrest adjustment mechanisms, seat cushions, lumbar support, subframe and seat bracket mountings. The only attachments of significant structural concern are the seat bracket mounting areas. All other attachments are essentially nonstructural.

The design philosophy for the composite seat frame was to duplicate the existing part geometry in areas of interface with cushions, adjustment, and mounting hardware. Additionally, it was necessary to duplicate the bending stiffness of the aluminum frame as closely as possible. Stiffness matching was desirable because current loads are in part based on the transmissibility of the aluminum frame. Increasing stiffness of the frame will also increase driver response loads. Reducing the frame stiffness significantly will allow contact with the hull (torsion bar cover #3 and/or floor plate) which will also raise driver response loads.

Initial attempts to utilize 100% E-glass fiber reinforcement in the composite frame were unsuccessful due to its low elastic modulus. The correct bending stiffness was achieved by increasing the height of side flanges. Stiffness requirements were met through a combination of material selection and geometry changes which maintain fit, form, and function while minimizing cost impact.

The key to meeting the stiffness requirement was redesigning the flanges by increasing their height by 1/2 inch and placing unidirectional graphite reinforcement in the upper 1 inch region. The increased flange height is not noticeable to the driver; as the upper edge is still well below the cushion surface. The amount of graphite fiber is kept to an acceptable amount (about 1 lb.) for cost considerations. The stiffness and geometry comparisons are detailed in Figure 7-13. Figure 7-14 shows the NISA finite element model of the seat frame which was used to check stress levels and calculate the natural frequency.

The strength issues of the seat frame were localized stress concentrations at the lower and upper attachment points on the vertical flanges. A well designed composite component has increased fastener spacing and edge margins when compared metallic designs. Achieving optimal composite design would have required a redesign of interfacing hardware as well as further reduction in hull clearance in critical areas. The best way to satisfy the strength requirements in these areas was to embed layers of stainless steel shim stock in the upper and lower extremes of the vertical flanges. The existing hole, spacing, and edge margins were maintained.

The critical detail was the square cutout located in the upper left flange. Stress analysis is presented in Figure 7-15. This cutout reacts 100% of the moment generated at the hinge line by the upper backrest. The minimum throat distance is .6 inch at two locations. The three .020 inch shims react approximately 70% of the load through this section due to their much higher stiffness. This is sufficient to allow the remainder to be carried by the surrounding composite material.

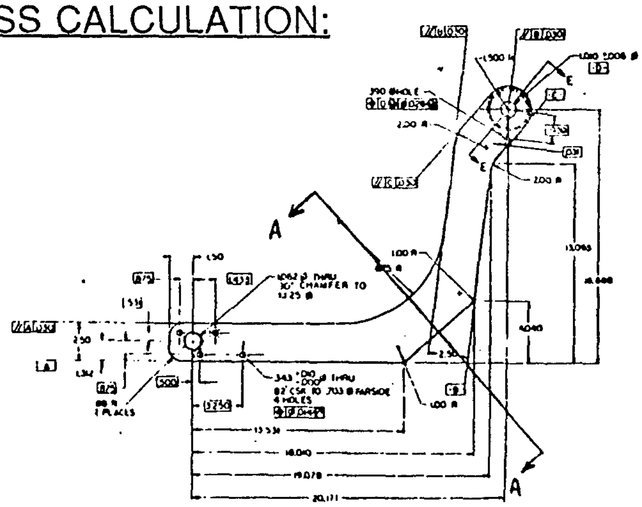
COMPONENT: SEAT FRAME

TEMPERATURE: ROOM TEMPERATURE

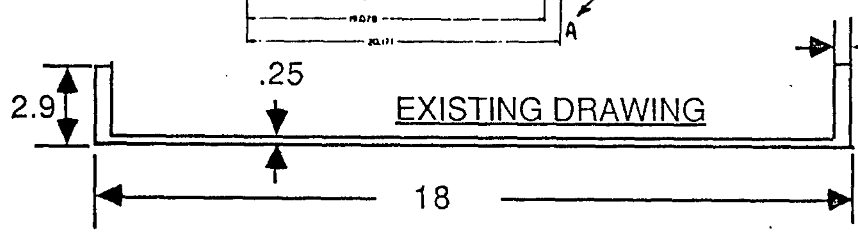
MATERIALS: EXISTING DESIGN: 5454 - H32 ALUMINUM PER DRAWING #12287601

COMPOSITE DESIGN: GLASS / GRAPHITE / VINYL-ESTER PER DWG. # 12287601-X

STIFFNESS CALCULATION:

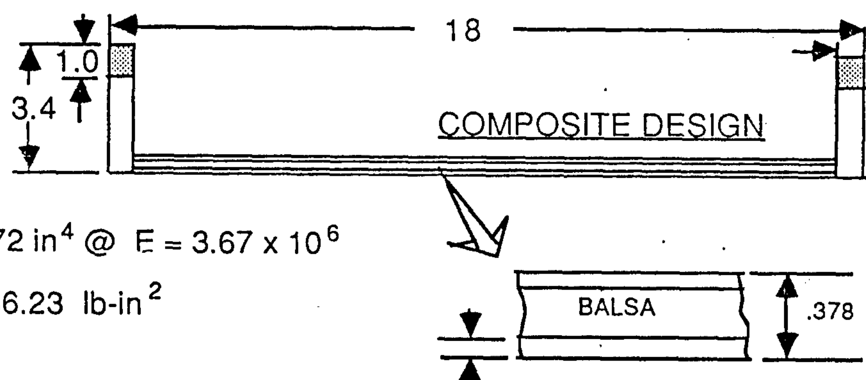


STIFFNESS WILL BE COMPARED AT SEC. A-A



5432 - H32
$E = 10.3 \times 10^6$ psi
per MIL - H - 5C
$I = 3.538\ in^4$

BENDING STIFFNESS $(EI) = 36.4 \times 10^6$ lb-in^2



GRAPHITE REINFORCED
$E_X = 15 \times 10^6$psi

SOLID SIDE RAIL
$E_X = 2.73 \times 10^6$ psi

$I = 9.872\ in^4$ @ $E = 3.67 \times 10^6$

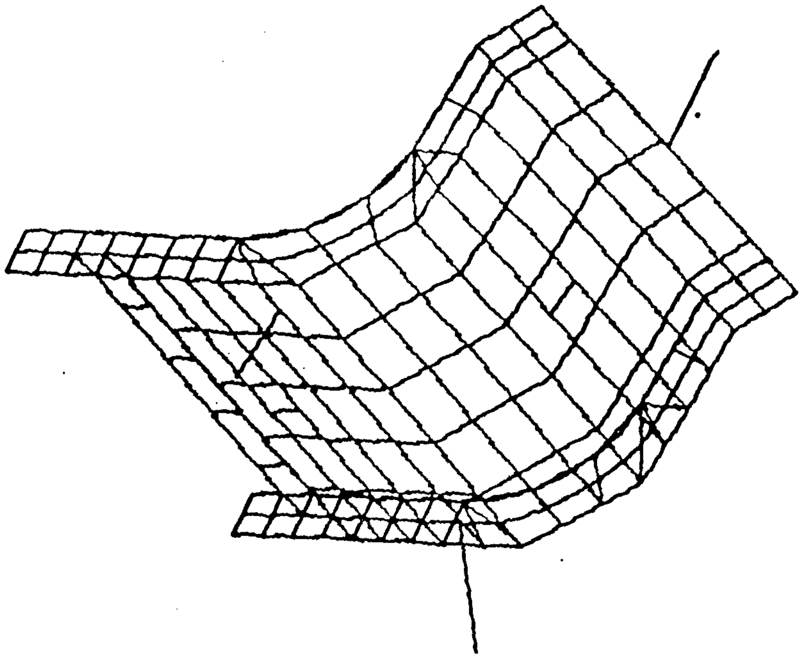
$E\,I = 36.23$ lb-in^2

.064 FACE SHEETS $E_X = 3.67 \times 10^6$

$\therefore$ COMPOSITE DESIGN IS WITHIN 1% OF EXISTING ALUMINUM STIFFNESS

Figure 7-13. Seat Frame Stiffness Analysis

FINITE ELEMENT ANALYSIS: NISA II PC



MODEL: 508 NODES
199 ELEMENTS

LOAD CASE 1: 234 LBS (SEAT BOTTOM)
168 LBS (SEAT BACK)
15G VERTICAL - SEAT IN RECLINED POSITION

LOAD CASE 2: 234 LBS (SEAT BOTTOM)
168 LBS (SEAT BACK)
15G HORIZONTAL - SEAT IN UPRIGHT POSITION

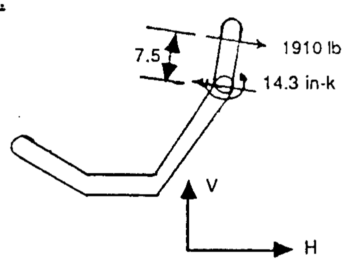
Figure 7-14. Seat Frame Finite Element Model

COMPONENT: SEAT FRAME

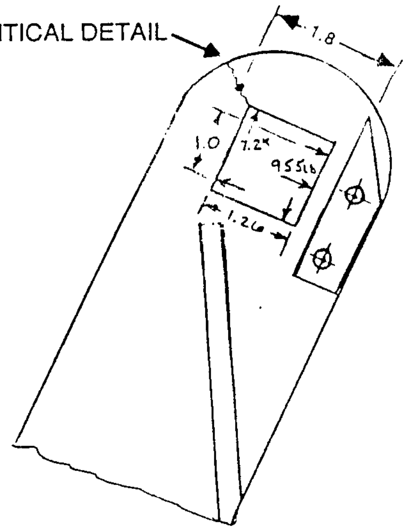
TEMPERATURE: ROOM TEMPERATURE

MATERIALS: GLASS / POLYESTER
STEEL SHIM
PER DRAWING # 12287601-X

LOADING:



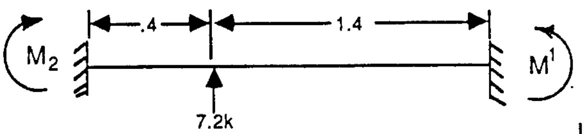
CRITICAL DETAIL



LOADS ARE 15G AND INCLUDE
F.S. = 1.5

STRESS CHECK:

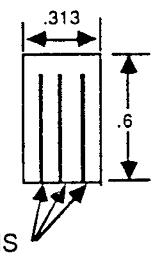
FIXED-FIXED BEAM ANALOGY (CONSERVATIVE)



$$M_2 = \frac{7.2 \times 1.4^2 \times .4}{1.8^2}$$

$$M_2 = 1.74 \text{ in-k}$$

CRITICAL DETAIL



0.020
STEEL SHIMS

$$M_C = M \times \frac{t\,E_{COMP}}{t\,E_{TOTAL}}$$

$$t\,E_{COMP} = .25 \times 3E6 = .76E6$$

$$t\,E_{TOTAL} = .76 + .06 \times 30E6 = 2.56E6$$

$$M = 1.74 \times \frac{.76}{2.56} = .52 \text{ in-k}$$

MAX BENDING STRAIN (ϵ_{MAX}) = $\frac{6M}{t h^2 E} = \frac{6 \times .52}{.25 \times .6^2 \times 3E6} = 1.1\ \%$

ALLOWABLE STRAIN (ϵ_{ALLOW}) = 1.5 %

MARGIN OF SAFETY = $\frac{1.5}{1.1} - 1 = \underline{\underline{+\ .36}}$

Figure 7-15. Seat Frame Critical Joint Detail

7.4. Material Selection.

The materials chosen for the composite driver's seat were optimized for strength, heat resistance, and cost. All materials chosen are available at reasonable cost in the quantities necessary to support M1A1 tank production.

7.4.1. Resin. Matrix selection was a critical decision in the composite driver's seat design. Resins were evaluated on the following criteria: suitability for resin transfer molding, a $-25^{o}F$ to $+140^{o}F$ operating temperature, a $+200^{o}F$ storage temperature, self-extinguishing capabilities, compatibility with epoxy primers and epoxy finish coatings and availability.

The principle concern in choosing the resin matrix for use in the fabrication of the composite driver's seat was the $-25^{o}F$ to $+140^{o}F$ operating temperature and the $+200^{o}F$ storage temperature. An epoxy resin system, Tactix 123 with H31 hardener manufactured by Dow Chemical was selected. Properties for this resin system are summarized in Table 7-4. In addition to meeting the operating temperature requirements, the resin was self-extinguishing, had good wet-out properties which made it suitable for resin transfer molding, it was compatible with epoxy primers and CARC paint and was available in quantities sufficient for production at low cost.

Table 7-4. Properties of Dow Tactix 123/H31 Resin System

Viscosity at 90 °F	250 cps
Pot Life at 100 °F	1.0 hours
Glass Transition Temperature	306 °F
Flexural Strength	20.9 ksi
Flexural Modulus	397.0 ksi
Tensile Strength	11.1 ksi
Tensile Modulus	431 ksi
Elongation at UTS	5.7 %

7.4.2. Fiber. The fibers selected for the composite driver's seat were chosen on the basis of cost, strength, stiffness, density, and availability. Temperature has little effect on the fiber since the matrix resin will degrade at a much lower temperature and therefore was not a consideration in the fiber selection. Table 7-5 summarizes different fibers and their properties.

Table 7-5. Properties of Typical Composite Fibers

	Density (lb/in^3)	Tensile Strength (psi)	Tensile Modulus (psi)	Elongation to Break (%)	Cost ($)
E-Glass	.094	500,000	10.5×10^6	4.8	0.80–2.00
S-Glass	.090	665,000	12.6×10^6	5.4	3.50–5.00
Kevlar	.053	430,000	19.0×10^6	2.3	22
High Strength Carbon	.064	650,000	33×10^6	1.95	20–25
Intermediate Modulus Carbon	.0635	800,000	42×10^6	2.00	40–50
High Modulus Carbon	.067	456,000	52×10^6	0.75	40–60

E-glass was selected as the primary reinforcement for the composite driver's seat design. E-glass had the strength and the mechanical properties required for the design. It is lower in cost than the other fibers and is readily available from numerous companies and distributors. The E-Glass reinforcement selected was an 18 oz/sq. yard biaxial knitted fabric manufactured by Cofab.

For the seat frame, Hexcel GA090, 8 oz/sq. yard unidirectional graphite fabric was used along the leading edge of the seat frame rails. This material was required so that the stiffness of the composite seat frame would match that of the aluminum seat.

7.4.3. Core. Core materials are used in structures to provide increased stiffness at reduced weight. One result to this type of construction is that the resulting sandwich is thicker than a monolithic construction. However, this factor did not adversely impact the design and space claim of the composite driver's seat.

Core materials were incorporated in the driver's seat design in the cushion areas of the seat frame and seat back to increase the weight savings. The side rails of the seat frame and seat back were of solid construction because they needed to retain high strength and structural integrity. This was required so that adjustment hardware, fasteners, and metal framework would not damage or pull through the composite material.

For the composite driver's seat program, core materials were evaluated on their density, cost, moduli, compressive strength, availability, and suitability to wet fabrication processes. Several core materials were available for use in composite sandwich construction, including aluminum and paper honeycombs, structural foams, and end-grain balsa wood. The properties of these materials are given in Table 7-6.

Table 7-6. Properties of Core Materials

	Hexcel 2024 Aluminum Honeycomb	Hexcel HRH10 Nomex	Rohacell 71WF Foam	Blatek Balsa Core 6.0 lb/ft^3
Modulus (ksi)	200	60	15	16
Compressive Strength (psi)	810	1075	213	84
Density (lbs/ft^3)	5.0	6.0	4.4	6.0
Cost	Very High	High	Mod	Low
Suitable to Wet Molding Process	No	No	Yes	Yes

Generally honeycombs are lightest in weight and offer the highest strengths, but they are also the most expensive and are not applicable to the wet molding processes. Honeycombs were not considered for use because of these attributes. Structural foam is lighter than end-grain balsa wood but higher in cost. The physical properties of the two are similar to each other.

End grain balsa wood was used as the core material for the driver's seat design. The balsa wood has properties which satisfied the structural requirements at a low cost. Balsa is available in large quantities and is compatible with wet molding processes. Balsa can withstand continuous temperatures of 350oF with no structural degradation and is self-extinguishing. A balsa wood from Baltek with a density of 6 lb/ft^3 was selected for the composite driver's seat program.

7.4.4. CARC Paint and Primers. Materials used for the composite drivers' seats were compatible with epoxy primers and Chemical Agent Resistant Coating (CARC) in accordance with MIL-STD-193. The painting was performed in the Composites Laboratory at the GDLS Troy Technology Center (TTC).

7.5. Composite Processing

The choice of an appropriate fabrication process played an important role in the successful execution of the driver's seat program. While there are many processes available in the composites industry, only a few are applicable to the composite driver's seat design. The fabrication approach employed used two major composite processes: resin transfer molding (RTM) and squeeze molding. The molds, which were procured from an outside supplier, were very similar in design despite utilizing two very different processes.

GDLS replaced five components from the current driver's seat assembly. These components comprise the majority of weight and/or cost of the driver's seat. The RTM process was used to fabricate the seat frame (P/N 12287602), while squeeze molding was used to fabricate the seat back (P/N 12287593), and access cover (P/N 12287651). The design of the two seat mounting brackets (P/N 12287570 and P/N 1228751) were optimized and remachined from existing forgings. The geometry of each redesigned component remained nearly the same as the current design. This allowed the composite driver's seat to utilize the current cushions, metal hardware, and most of the same fasteners to ensure the same form, fit, and function as the current metallic seat.

7.5.1. Seat Brackets. The current seat mounting brackets (P/N 12287570 and P/N 12287571) are 4130 or 4140, Class D, steel forgings conforming to MIL-S-46172. These brackets were maintained for the composite driver's seat program with some design alterations. GDLS analysis showed that seat brackets made from composite materials, which would reduce weight and satisfy strength and envelope requirements, could not be successfully fabricated.

A weight savings was still obtained by optimizing the current mounting bracket designs. The current seat mounting brackets were redesigned and optimized for strength. The brackets were then remachined and unnecessary material was eliminated. This resulted in a 26 percent weight savings for the left bracket and a 36 percent savings for the right bracket. The resulting weight reduction for both mounting brackets 7.3 pounds.

7.5.2. Access Cover. The seat access cover (P/N 12287651) was fabricated using the squeeze molding process. This process is basically a closed-mold, low-pressure process that does not require the use of external or injection machinery to impregnate the reinforcement fibers (Figure 7-16). The low pressures used in the process allowed the mold to be constructed of low cost reinforced epoxy rather than steel. A picture of the access cover mold is shown in Figure 7-17. With the squeeze molding process there is a small amount of cleanup required; however, the absence of expensive machinery makes it a cheap and simple process.

The cover was constructed of 18 oz. Cofab knitted E-glass reinforcement and Dow Tactix 123/H31 epoxy resin. Each of the mold halves were prepared with Frekote B-15 mold sealer and Frekote 44 mold release. The dry reinforcement fiber was then cut to shape, impregnated by hand with resin, and loaded in the female mold half. The mold was then closed and the part cured. After removal from the mold, the part was trimmed and CARC paint applied.

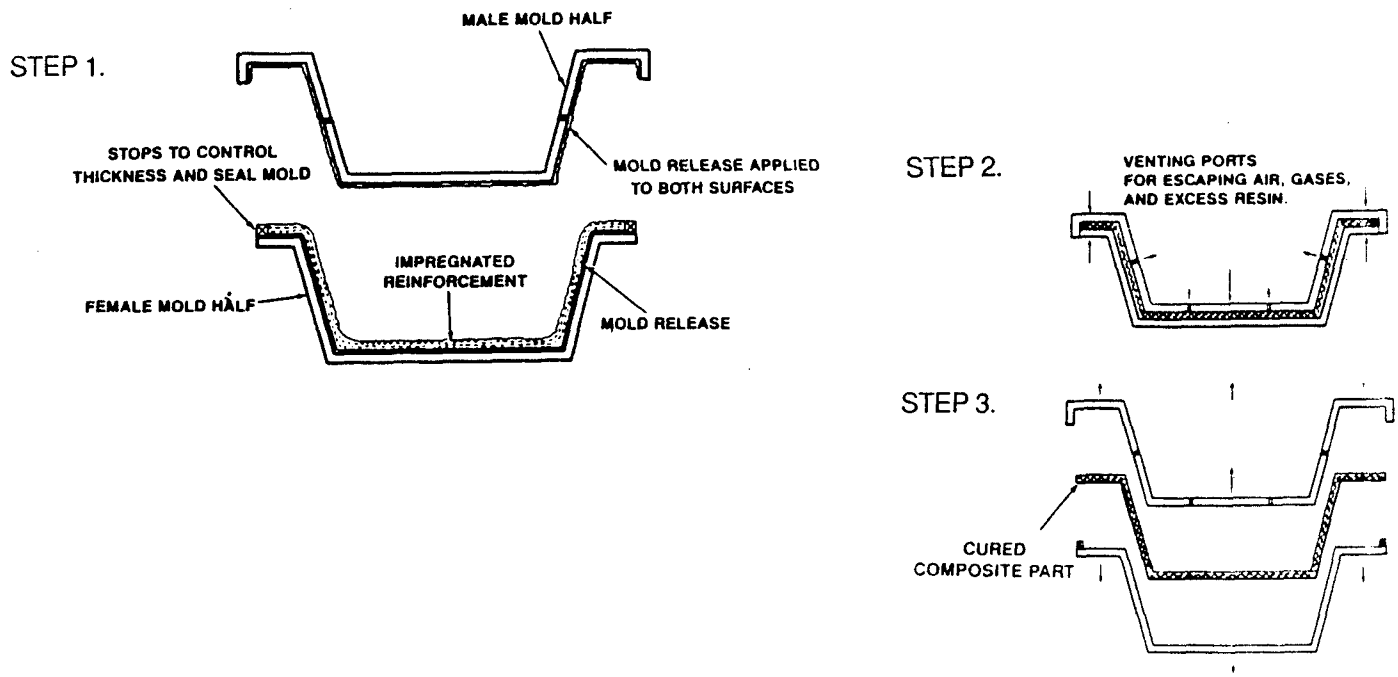


Figure 7-16. Schematic of Squeeze Molding Process

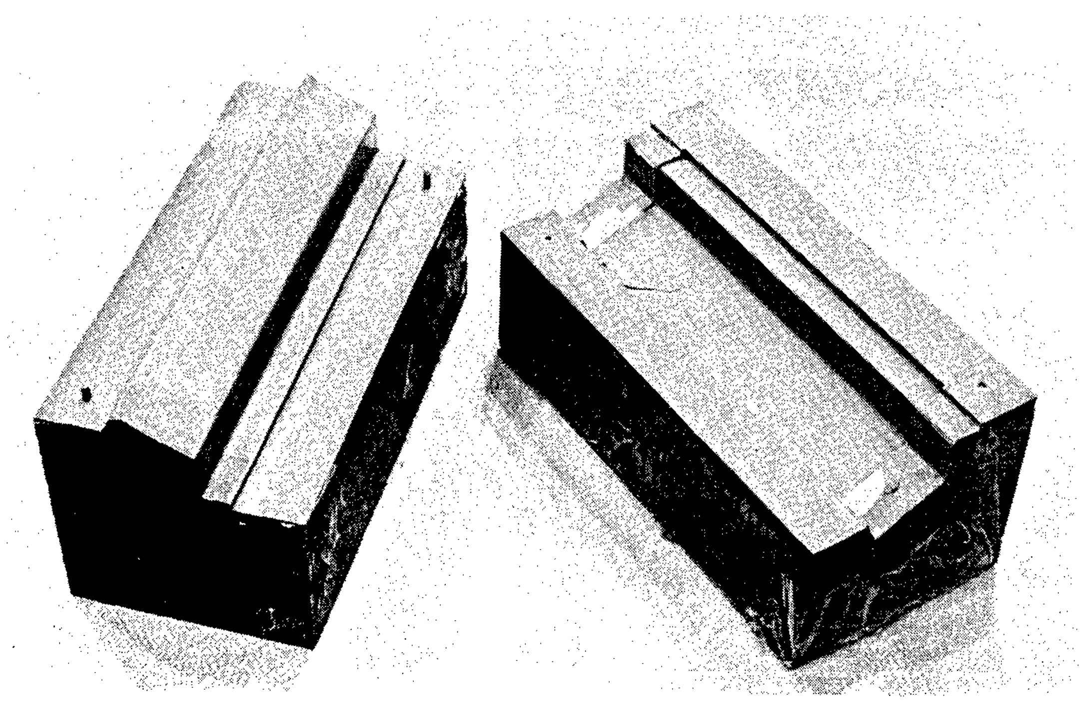


Figure 7-17. Picture of Access Cover Mold

7.5.3. Upper Backrest. The upper backrest (P/N 12287390) of the driver's seat assembly was fabricated using the squeeze molding process with a reinforced epoxy mold. A picture of the mold appears in Figure 7-18.

The fiber used was an 18 oz. Cofab knitted E-glass fabric and the resin was Dow TACTIX 123/H31 epoxy resin system. Each mold half was prepared with Frekote B-15 mold sealer and Frekote 44 mold release. The dry reinforcement fiber and the Baltek balsa wood core were then cut to shape, impregnated with resin, and loaded in the female mold half. The mold was then closed and the part cured. After removal from the mold, the part was trimmed, the required holes were drilled, and CARC paint applied.

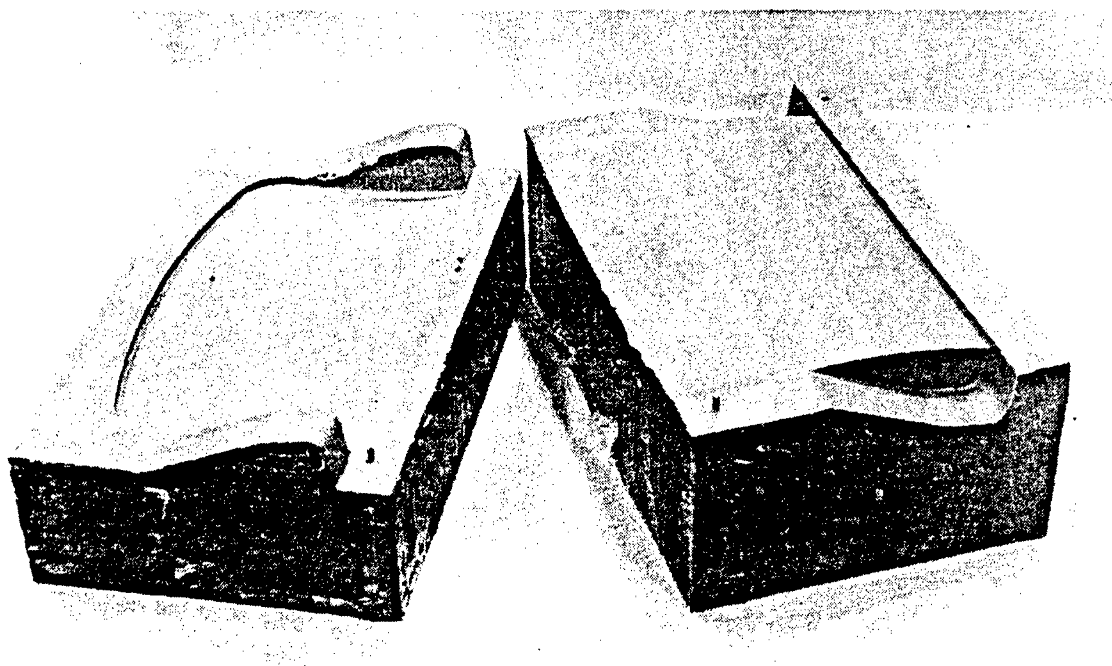


Figure 7-18. Picture of Upper Backrest Mold

7.5.4. Seat Frame. The fabrication of the seat frame (P/N 12287601) for the driver's seat assembly was performed using the resin transfer molding process (RTM). Resin transfer molding

(RTM) is a close-mold, low-pressure process in which the dry reinforcement fiber is impregnated with resin in the cavity of the mold. The RTM process is illustrated in Figure 7-19.

The fiberglass reinforced epoxy RTM mold was comprised of two sections, a male half and a female half. A picture of the mold is shown in Figure 7-20. The top (male) half of the mold had four vents which allowed air, gases, and excess resin to escape from the mold cavity during the resin injection process. Each of these four vents were fitted with flexible plastic tubing which were crimped shut to allow the part to cure in a sealed environment. The bottom (female) half of the mold contained the resin injection point.

The dry fiber reinforcement, balsa wood core, and the pre-cured inserts were cut to shape and loaded on the male half of the mold. The mold halves were closed and held together in a hydraulic press. The resin was injected from the bottom half of the mold, impregnating the dry fiber within the cavity of the mold. The vents were closed once the entrapped air had been removed from the mold cavity. Heat was then applied to the mold to cure the part. The part was then removed from the mold, trimmed, drilled, painted, and assembled.

Pre-cured composite inserts were made of 18 oz. Cofab E-Glass, Dow Tactix 123/H31 epoxy resin, and .020" steel shim stock. The inserts were hydrodynamically cut from a large .180" thick panel which contained 6 shims staggered within the layup (Figure 7-21). The geometry of the seat frame and seat frame mold required that inserts be utilized to obtain the desired material thickness in the frame rails.

The main reinforcing fabric used to make the driver's seat frame was 18 oz. Cofab E-glass. In the seat frame rails 8 oz. Hexcel unidirectional graphite fabric was used in addition to the Cofab. Graphite was required in this area to provide additional strength and stiffness.

Loading of the dry fiber reinforcement, balsa wood, and inserts into the mold was the most critical step in the seat frame fabrication process. First, patterns were established for cutting the dry reinforcement and the balsa core. Next, the required patterns were cut from the respective reinforcements and balsa wood. The glass reinforcement plies were then positioned on the male half of the mold, the balsa wood cores added, and the inserts put in place. The graphite plies were then sewn into their required positions between the E-glass plies along the leading edges of the frame rails. The edges of the E-glass plies were brought together over the centerline of the part and sewn tightly to assure that they would not move when closing the mold halves or injecting the resin. Before closing the mold, any loose strands of reinforcement were trimmed away to ensure that a good seal was obtained between the two mold halves.

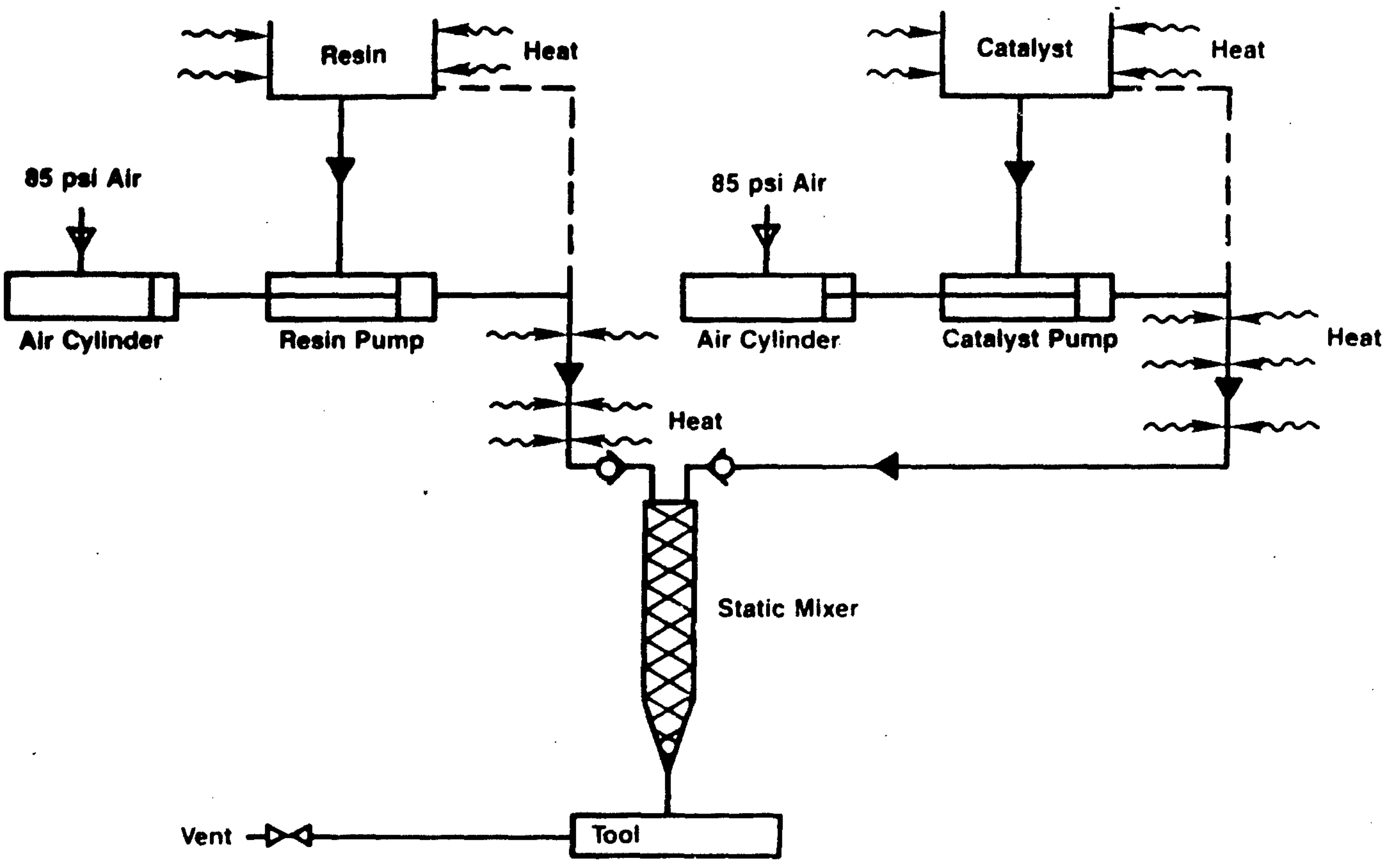


Figure 7-19. Schematic of RTM Process

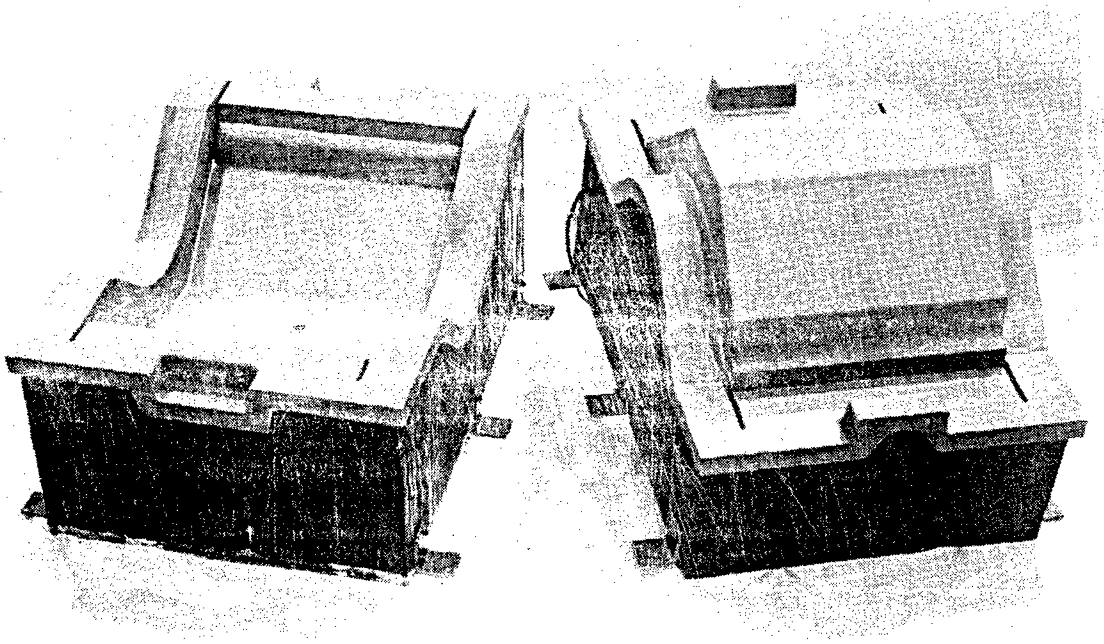


Figure 7-20. Picture of Seat Frame Mold

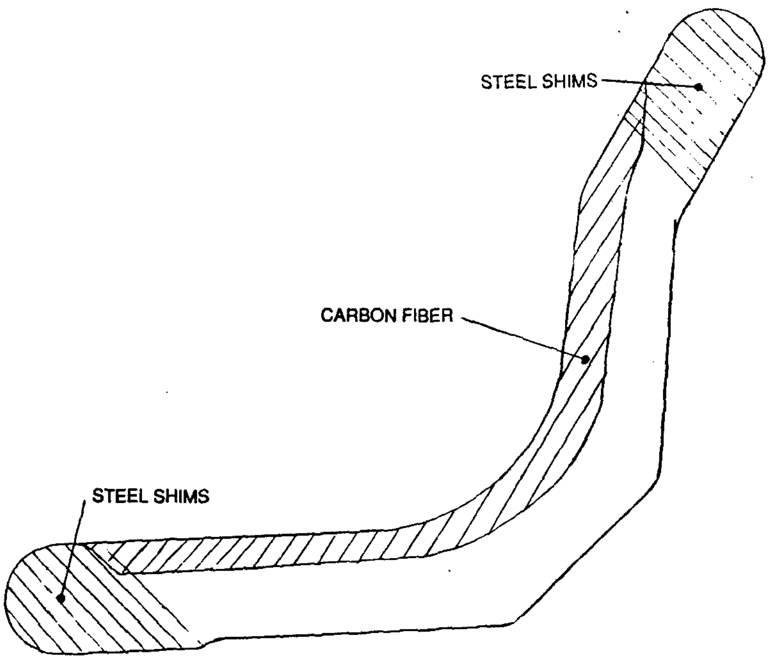


Figure 7-21. Seat Frame Side Rail Details

7.6. Final Assembly

For the three prototype drivers' seats, the assembly process began by disassembling the required components from current metallic driver's seat assemblies. Because the cross-sectional thickness of the composite seat components is greater in some areas than their metallic counterparts, it was necessary to make minor changes to some of the existing components. One example of this is the bolts which were used to secure the seat cushions to the seat frame had to be replaced with longer versions. The same was true for numerous other fasteners which had to be lengthened to compensate for the increased material thicknesses.

A few other existing components required minor modifications. The seat subframe, for example, had to have approximately .063" of metal removed from the outside of its two slotted ears to fit and function properly with the composite seat frame. Only one new component, the bracket which supports the seat height adjustment lever, had to be fabricated. On the current seat this bracket is welded on to the seat frame. On the composite seat, this bracket was machined from aluminum and designed such that small bolts could be used to fasten the bracket to the seat frame. Other then the items mentioned above, assembly of the composite seats is identical to that for the current drivers' seats.

8.0. WEIGHT SUMMARY

The contract called for a minimum weight reduction of 12.4 lbs. A weight reduction of 19.9 lb. was achieved which is 19.4 percent of the total assembly weight. An individual breakdown for each of the five redesigned components is provided in Table 8-1. It is significant to note that on a component basis, weight reduction averaged 39.1 percent.

Table 8-1. Weight Reduction Summary

COMPONENT	CURRENT PRODUCTION	REDESIGNED ACTUAL	WEIGHT SAVINGS
Seat Frame	18.5	11.7	6.8
Seat Back	4.9	2.9	2.0
Access Cover	4.6	0.8	3.8
Left Mounting Bkt.	13.2	8.4	4.8
Right Mounting Bkt.	9.7	7.2	2.5
TOTAL	50.9	31.0	19.9

9.0. TESTING

The design verification method selected was to subject each redesigned component to finite element and/or conventional stress analysis. Sufficient funding remained in the contract after delivery of the three completed assemblies to perform limited laboratory testing. Basic shock, vibration, and static tests were conducted at Warren Test Center of GDLS.

The driver's seat assembly was mounted to a shock/vibration test machine using a hull simulating interface fixture. Shock impulses were imposed on the fixture. Accelerometers located on the fixture, seat, and 95th percentile dummy recorded dynamic response to the shock inputs. Figure 9-1 shows the basic shock and vibration test setup.

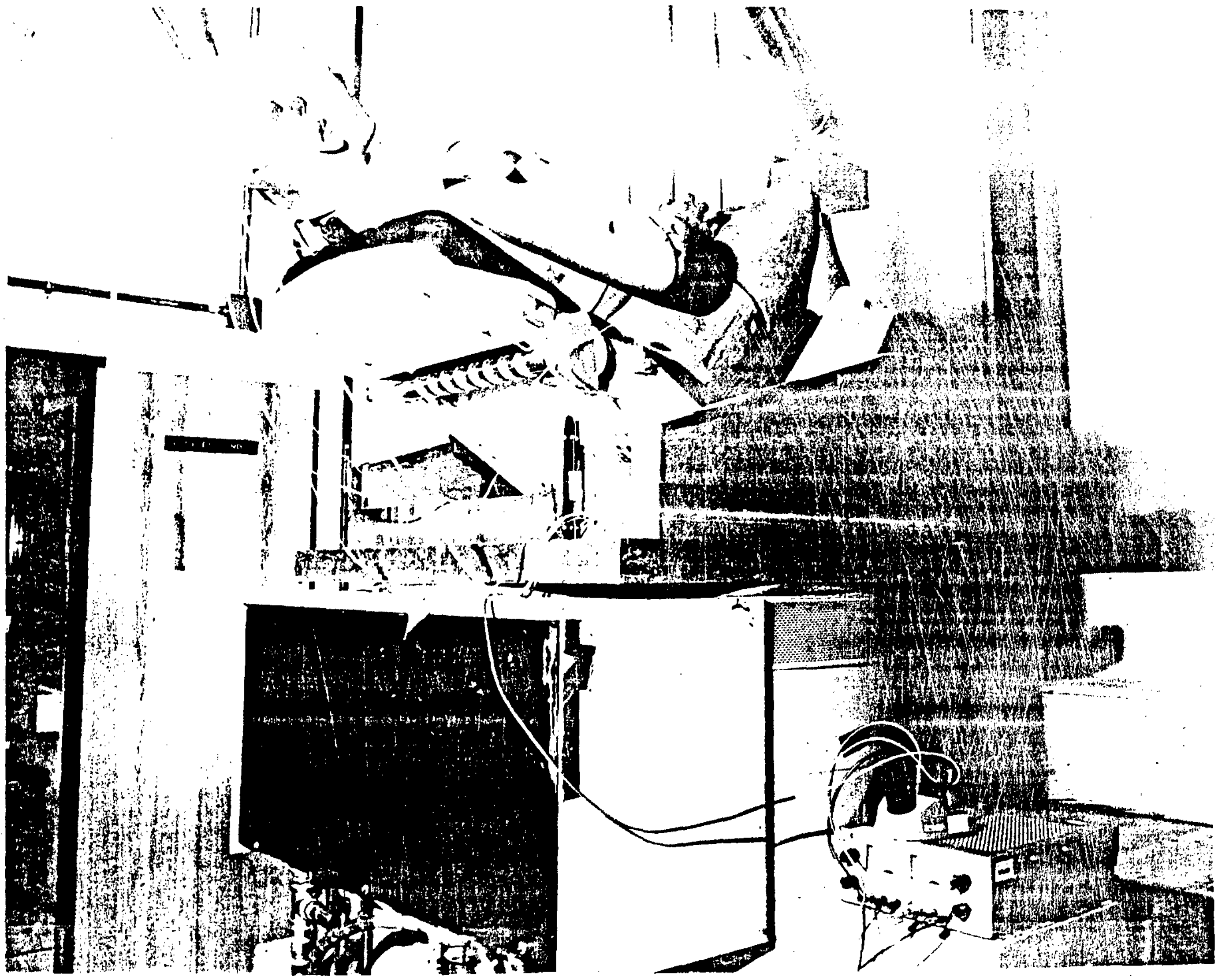


Figure 9-1. Shock and Vibration Test Setup

The dummy was leased from Transportation Research Center of Ohio for the duration of the test. Although its delivered weight was 210 lbs. (233 lbs. was desired), it was used as is because the head and lower legs were supported by the driver's seat during testing. Actual driver's head and lower legs are supported by a hull mounted headrest and floor plate respectfully.

9.1. Basic Shock

The driver's seat assembly with dummy was subjected to three half sine shock pulses in each direction of each of the three mutually perpendicular axes for a total of 18 shocks. Peak amplitude was 30 +/- 3g, at 11 +/-1.1 ms as specified by MIL-STD-810. A typical shock waveform was recorded for each of the three mutually perpendicular axes. In addition, seat frame deflections were recorded under the seat bottom using soft clay and under the upper backrest using a linear potentiometer. No seat damage was detected. The maximum acceleration recorded for the dummy during the testing was 6g longitudinal.

9.2. Frequency Scan

The driver's seat assembly with dummy was subjected to a 1g impulse at frequencies ranging from 5 hz to 500 hz. This test was then repeated without the dummy. Seat response was recorded for comparison to the input value of 1g. The purpose of this test was to determine resonant frequencies. Free play in the seat adjustment mechanism made it difficult to interpret the data, but 5 hz and 375 hz appeared to induce resonance.

9.3. Static Testing

The seat assembly, while still mounted to the test fixture, was statically loaded to 4g (932 lbs.) using bags of lead shot. Defections at the critical location were recorded before and after testing and are provided in Table 9-1.

A complete test report is provided in the Appendix.

Table 9-1. Load Versus Displacement for Static Test

Load	Displacement
100	0.147
200	0.598
300	1.047
400	1.149
500	1.215
600	1.245
700	1.284
800	1.319
900	1.343
936	1.353

10.0. ECONOMIC ANALYSIS

An economic analysis has been performed to compare the potential production costs of the composite driver's seat with the current seat assembly. The average unit cost (AUC) for the current production aluminum driver's seat was obtained from the GDLS Material Resource Planning (MRP) system. The MRP cost does not include GDLS profit, G&A, or overhead.

The composite driver's seat cost analysis was based on a production rate of 750 units annually on a one-shift, 8-hour, 5-day work week (1-8-5). All costs are expressed in constant FY88 dollars using January 1988 production start-up date and development costs were considered "sunk" and not included in the analysis.

The bottom-up cost estimating model was used in the economic analysis for the composite driver's seat. This approach is derived from standard pricing methodology where each cost element is identified and defined. The unit cost and labor associated with each element were then estimated and an average unit cost derived.

The cost estimates for the composite driver's seat were derived by GDLS engineering. Material costs were calculated from current vendor process and actual material used in developmental part fabrication. The costs for some of the current seat components were estimated and are noted as such. Labor and tooling were determined from the knowledge and experience gained in the research and development of the composite driver's seat.

10.1. Nonrecurring Costs

The nonrecurring cost elements consisted of two types: nonrecurring investment (capital equipment) and nonrecurring labor.

The cost of capital equipment required to support production was not included since the purchase of separate capital equipment under a program of this size would be difficult to justify. The primary capital equipment required to support production is listed below:

25-ton molding press (2)
35-ton molding press (1)
3 mold heaters (oil, steam, etc.)
resin transfer molding machine (1)
post cure oven (1)
CARC paint spraying booth (1)

In addition to the above items, numerous other capital equipment items such as powered screwdrivers, powered wrenches, assembly benches, mold cleaning tools, and electric drills would be required to initiate and support production. All other assumptions made in the economic analysis for each cost element are stated in the calculations.

The estimated nonrecurring engineering labor (shown below) is the labor required to set up the initial production facilities. Based on a total production of 4500 units, the cost per unit is $3.91.

Equipment and tooling acquisition	200 hours
Facilities engineering	160 hours
Design Engineering	80 hours
Total nonrecurring eng. labor	440 hours

Initial production facilities:

This element covers the cost of nonrecurring engineering tooling (molds, fixtures, and templates) and nonrecurring labor (equipment, tool installation, and tryout).

The following assumptions were used in development of the tooling costs:

- The models used in fabricating the prototype tools will be available for production tooling fabrication
- Production tools (molds) will last for the complete production run.
- Tooling costs will be amortized over the complete production run per unit basis (4,500 units).

The estimated cost of nonrecurring production tooling is summarized below. These costs include all labor and materials used in the fabrication of that tool. Based on a production of 4,500 units over six years, the average cost of tooling per unit is approximately $32.22.

Seat frame mold	$ 50,000
Pre-cured insert mold (6 cavity)	$ 25,000
Seat back mold	$ 35,000
Access cover mold (2 cavity)	$ 25,000
Drill fixtures: seat frame	$ 6,000
Drill fixture: seat back	$ 1,000
Drill fixture: access cover	$ 2,000
Cutting fixture: access cover	$ 500
Cutting templates	$ 500
Total Nonrecurring tooling	$145,000

The production nonrecurring labor costs are summarized below. Based on production of 4500 units, the nonrecurring labor cost is $4.82 per unit.

Facility setup	160 hours
Equipment installation	160 hours
Tool and equipment tryout	300 hours
Total nonrecurring labor	620 hours

10.2. Recurring Production Tooling

The cost of recurring production tooling is summarized below. Based on production of 4,500 units over six years, the average cost of recurring tooling per year is $12.27.

Drill bits and countersinks	$ 25,920
Router bits	$ 2,295
Sanding disks	$ 765
Diamond cut-off wheels	$ 18,000
RTM replacement parts	$ 3,375
Hole saws	$ 4,860
Total recurring tooling	$ 55,215

10.3. Production Costs

This element includes costs directly associated with manufacturing the composite driver's seats. These costs are divided into the following categories: manufacturing, recurring engineering, tool maintenance and quality control.

The manufacturing costs consists of both material and labor expenses associated with the fabrication of the composite components and the final assembly of a complete seat assembly. The material costs for the composite driver's seat are shown in Table 10-1.

Table 10-1. Production Material Costs

COST ITEM	AMOUNT	UNIT COST,$	COST $
Epoxy resin	4.3 lbs.	2.79	12.00
Epoxy hardener	0.8 lbs.	3.00	2.40
18 oz. glass fabric	10.6 lbs.	1.67	17.70
10 oz. glass fabric	0.9 lbs.	3.75	3.38
8 oz. carbon fiber fabric	0.15 lbs.	34.00	5.10
Balsa wood	0.6 lbs.	0.86	0.52
Mold sealer and release	0.03 gal.	25.46	0.76
New/replacement hardware	1 set	8.00	8.00
Steel shim stock	1 set	1.67	1.67
Seat brackets *	1 pair	368.51	368.51
Remaining seat hardware *	1 set	550.00	550.00
Nonrecurring engineering labor	0.09 hours	40.00	3.91
Manufacturing labor	3.3 hours	35.00	115.50
Recurring engineering labor	0.19 hours	40.00	7.60
Tool maintenance labor	0.26 hours	40.00	10.40
Quality control labor	0.32 hours	35.00	11.20
Nonrecurring tools (molds)	$145,000	32.22	32.22
Recurring tooling	$55,215	12.27	12.27
TOTAL COST	1 set	N/A	1163.14

*The estimated price is based on 1981 prices which have been increased 4% per year for inflation.

Table 10-2. Estimated Production Labor Hours

OPERATION	SEAT FRAME	SEAT BACK	ACCESS COVER*
Clean/prep mold	0.7	0.4	.4
Fabricate precured inserts	0.3	N/A	N/A
Cut materials/load mold	0.5	0.4	.3
Inject resin, cure	0.4	0.4	.3
Trim and deflash	0.1	0.1	.1
Machine and drill	0.3	0.2	.1
Paint	0.2	0.2	.2
Assembly	0.6	0.2	N/A
TOTAL	3.1	1.9	1.4 for 2

*Access covers are fabricated two at a time. Hour estimates are for two covers.

Recurring engineering includes the cost of all engineering effort in support of production. The labor required, which is detailed below, costs $7.68 per unit for the six-year production run.

Maintainability Engineering	4 hours/month
Production Engineering	8 hours/month
Total Recurring Engineering	12 hours/month

Tool maintenance costs included the labor associated with normal tool maintenance and the cost of tool replacement due to normal wear. The die maintenance labor required for the three composite components plus the pre-cured insert should be minimal given the steel molds and relatively low production volumes. The estimated labor required is detailed below. Based on the six-year production run, the average cost of tool maintenance will be $10.40 per seat.

Seat Frame Mold	5 hours/month
Seat Back Mold	4 hours/month
Access Cover Mold	4 hours/month
Precured Insert Mold	3 hours/month
Total Tool Maintenance Labor	16 hours/month

The quality control costs include the labor required to perform all functional checks, reliability testing, and incoming material inspection. Based on the six-year production total of 4500 units, the cost to perform the quality control functions is $11.20 per unit. The estimated labor hours for this cost item is detailed below:

Dimensional check	8 hours/month
Reliability testing	8 hours/month
Incoming inspection	4 hours/month
Total quality control labor	20 hours/month

APPENDIX

COMPOSITE DRIVER'S SEAT TEST REPORT

APPENDIX A

COMPOSITE DRIVER'S SEAT TEST REPORT

GENERAL DYNAMICS

LAND SYSTEMS DIVISION

ENGINEERING EVALUATION REPORT

COMPOSITE DRIVER'S SEAT

5 MARCH 1990

PREPARED BY: R. A. Pusdesris
R. A. PUSDESRIS
EVALUATION TEST

APPROVED BY: Don Schafer
D. E. SCHAFER
EVALUATION TEST

(D3-D6/90:ms)

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1.0 INTRODUCTION

In an attempt to deploy composite material structures on an M1A1 vehicle, a prototype composite driver's seat (P/N 12282830) was built. To evaluate the performance of this seat, an engineering evaluation test was conducted from 14 February through 20 February 1990. Testing consisted of the following:

- Basic shock (using an instrumented 95th percentile anthropomorphic device)
- Resonance sweep (with and without anthropomorphic device)
- Continuous 4g load

This report presents the data recorded during the test.

2.0 TEST CONDITIONS

The composite driver's seat assembly was mounted on a shock and vibration test fixture in the orientation which simulates actual vehicle installation. For shock and resonant frequency sweeps the height adjustment of the seat was set at its lowest location. The seat was then placed into either the reclined or upright position when exposed to dynamic inputs in the following directions:

- Vertical axis - reclined position
- Lateral axis - upright position
- Longitudinal axis - upright position

The driver response was measured by placing the instrumented 95th percentile U.S. male anthropomorphic device (dummy) in the driver's seat. Acceleration measurements were made using triaxial accelerometers implanted in the dummy's chest and pelvis cavities. The accelerometer axis orientation is fixed with respect to the dummy position (reclined or upright). However, these orientations do not correspond with the driver's seat axes orientation (Figure 1) due to the driver's seat being in a reclined position. Therefore, driver's response and seat input axes do not correspond. Test setup photographs are shown in Appendix A.

3.0 TEST RESULTS

3.1 Basic Shock

The driver's seat assembly with an instrumented anthropomorphic device was subjected to three half sine shock pulses in each direction of the three mutually perpendicular axes. The shock inputs were 30 $\pm$ 3g at an 11 $\pm$ 1.1 ms time duration. (Reference Appendix B for actual shock inputs.) Driver's responses were measured and recorded in real time. Peak response g's for each shock were measured and are listed in Table 1.

During vertical shock testing, seat deflection was measured. Two areas with minimum clearance with the hull floor were chosen for the deflection measuring points (Figure 2 shows the measurement locations). Deflection at D1 was measured using putty and feeler gauges while deflection at D2 was measured using a linear motion potentiometer. Maximum deflections measured were approximately 0.070" for D1 and 0.450" for D2.

At the completion of basic shock testing the performance of the seat adjustment mechanisms were checked and showed no signs of performance degradation.

3.2 Resonance Sweep

A $\pm$ 1g vibration sweep from 5 to 500 Hertz was inputted to the mounting fixture while recording the composite seat's response. This response was measured with a triaxial accelerometer mounted on the right side of the seat. Responses were measured in all three directions with and without the anthropomorphic device in the driver's seat. Only one apparent resonant frequency at approximately 400 Hz was noticed. Refer to Appendix C for driver's seat response plots.

3.3 Continuous 4g Load

The composite driver's seat assembly was subjected to a continuous 4g load (936 lbs.) for a period of 5 minutes. The seat was placed in the reclined position and loaded by using bags of lead shot. The seat displacement at D2 was measured as the load was increased. Table 2 lists the seat displacement measurements versus load.

The strength of the driver's seat upper back rest was tested by applying a 250 lbs. continuous load for a period of 5 minutes. The back rest was placed in its fully reclined position and loaded to 250 lbs. At the completion of this continuous load test, the performance of the seat's adjustment mechanisms were checked and showed no signs of performance degradation.

TABLE 1 BASIC SHOCK DRIVER'S RESPONSE

Direction	Drop	DRIVER'S RESPONSE (PEAK g's)					
		Chest			Pelvis		
		Vert.	Long.	Lat.	Vert.	Long.	Lat.
Vert. (+)	1	.75	1.25	.75	1.00	1.8	1.5
	2	.85	1.25	.8	1.3	1.8	1.75
	3	.85	1.3	.75	1.5	2.1	1.9
Vert. (-)	1	2.7	5.1	1.9	2.7	4.0	2.5
	2	2.5	5.25	1.6	2.25	3.5	2.5
	3	2.5	5.4	1.5	2.25	3.25	2.4
Long. (+)	1	5.15	1.4	1.1	3.0	4.2	2.0
	2	4.9	1.0	1.5	3.2	4.3	1.9
	3	4.8	1.45	1.2	2.8	4.6	2.0
Long. (-)	1	5.5	4.0	1.5	4.8	5.5	3.4
	2	4.9	4.2	1.2	5.0	6.0	3.2
	3	5.3	4.0	1.1	4.9	5.8	3.5
Lat. (+)	1	1.3	1.7	3.5	1.0	5.0	7.0
	2	2.2	1.75	3.75	1.0	4.7	6.5
	3	2.6	1.55	3.5	1.5	5.2	6.4
Lat. (-)	1	3.25	1.0	3.6	1.6	1.2	9.1
	2	2.37	1.0	4.0	1.65	1.6	8.5
	3	2.1	.8	4.0	1.9	1.2	8.0

TABLE 2. CONTINUOUS 4g LOAD SEAT DISPLACEMENT

Load (lbs.)	Displacement (inches)
100	0.147
200	0.598
300	1.047
400	1.149
500	1.215
600	1.245
700	1.284
800	1.319
900	1.343
936	1.353

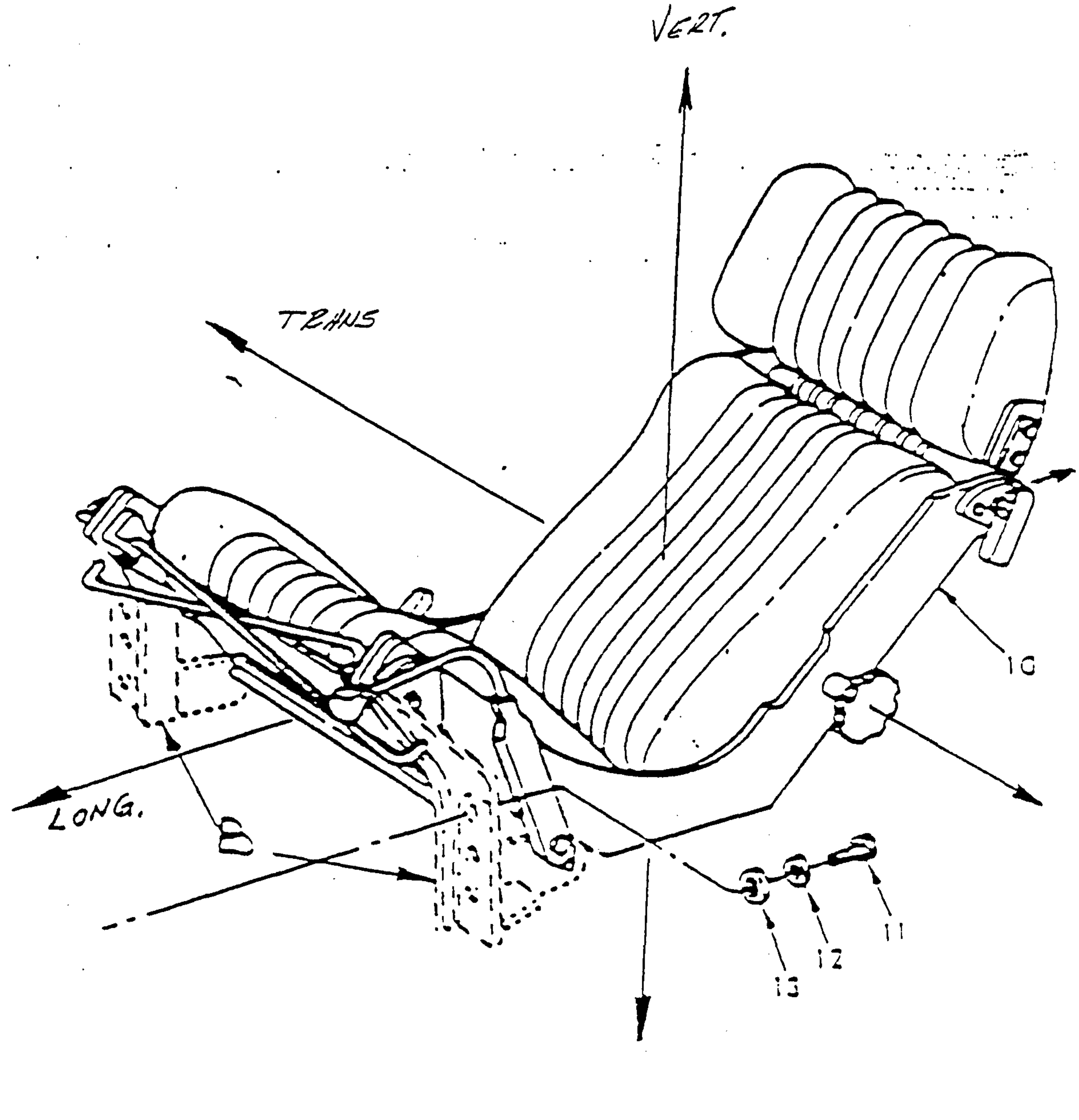


FIGURE 1: DRIVER'S SEAT AXES OF ORIENTATION

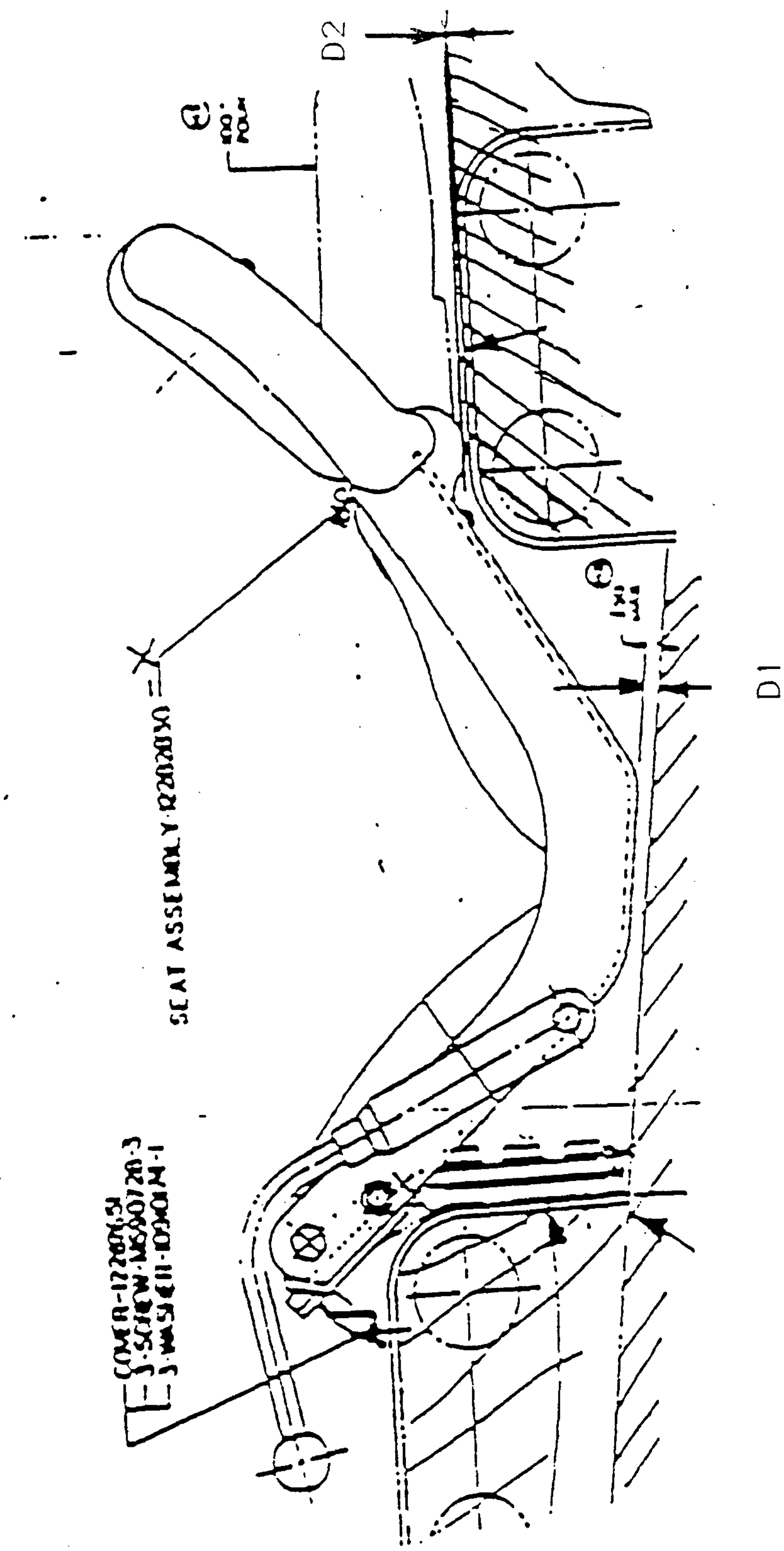
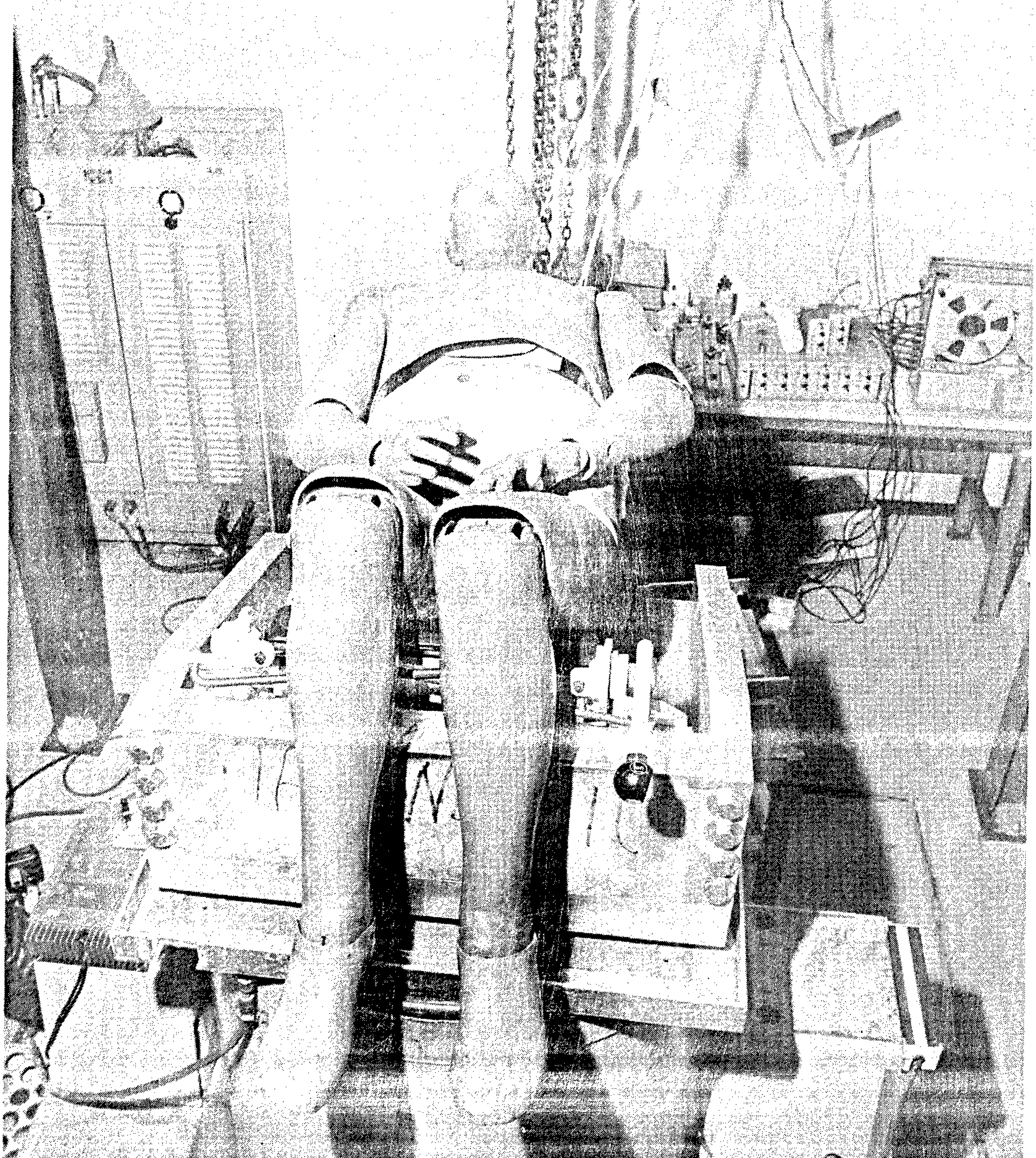
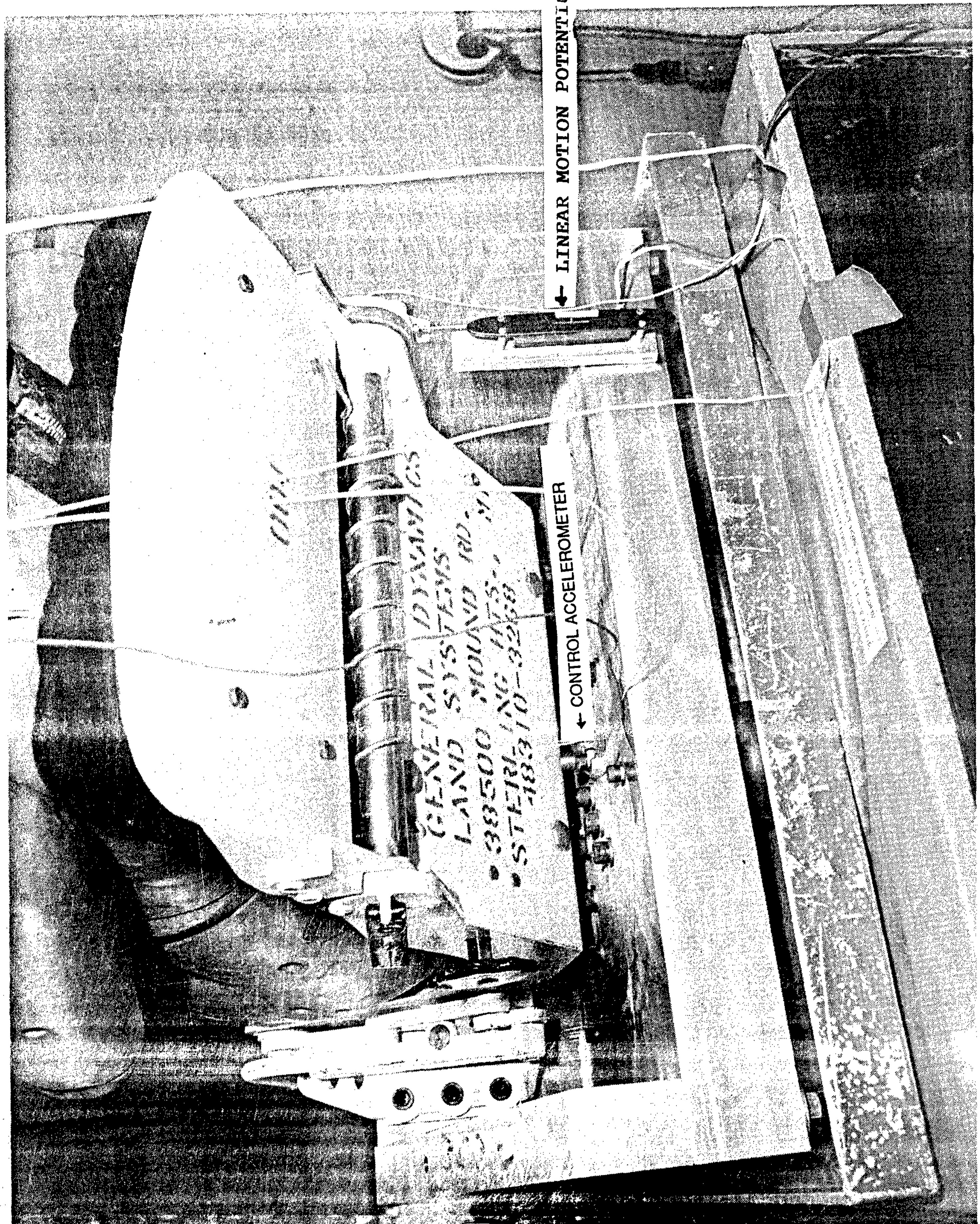


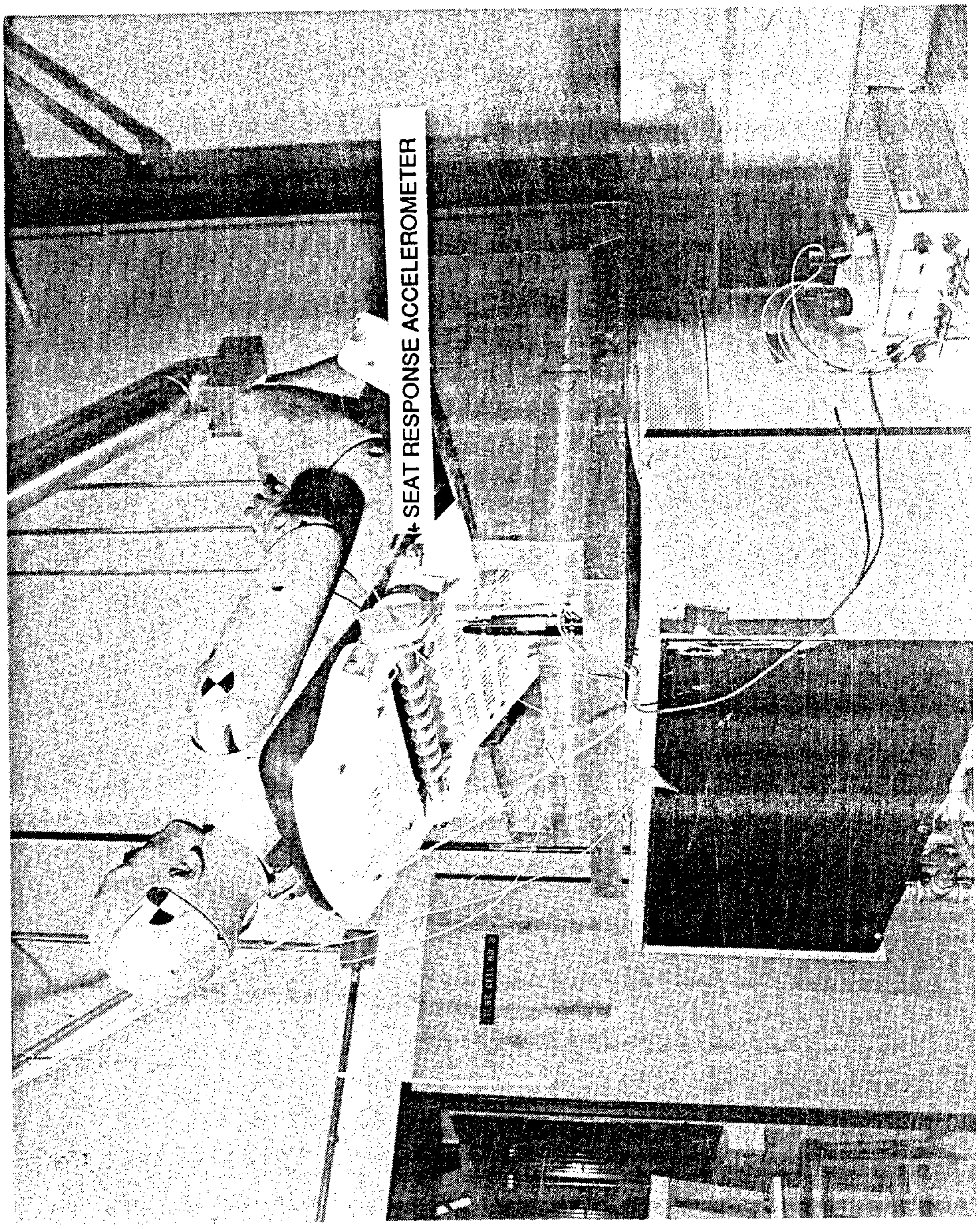
FIGURE 2 : DISPLACEMENT MEASUREMENT LOCATIONS

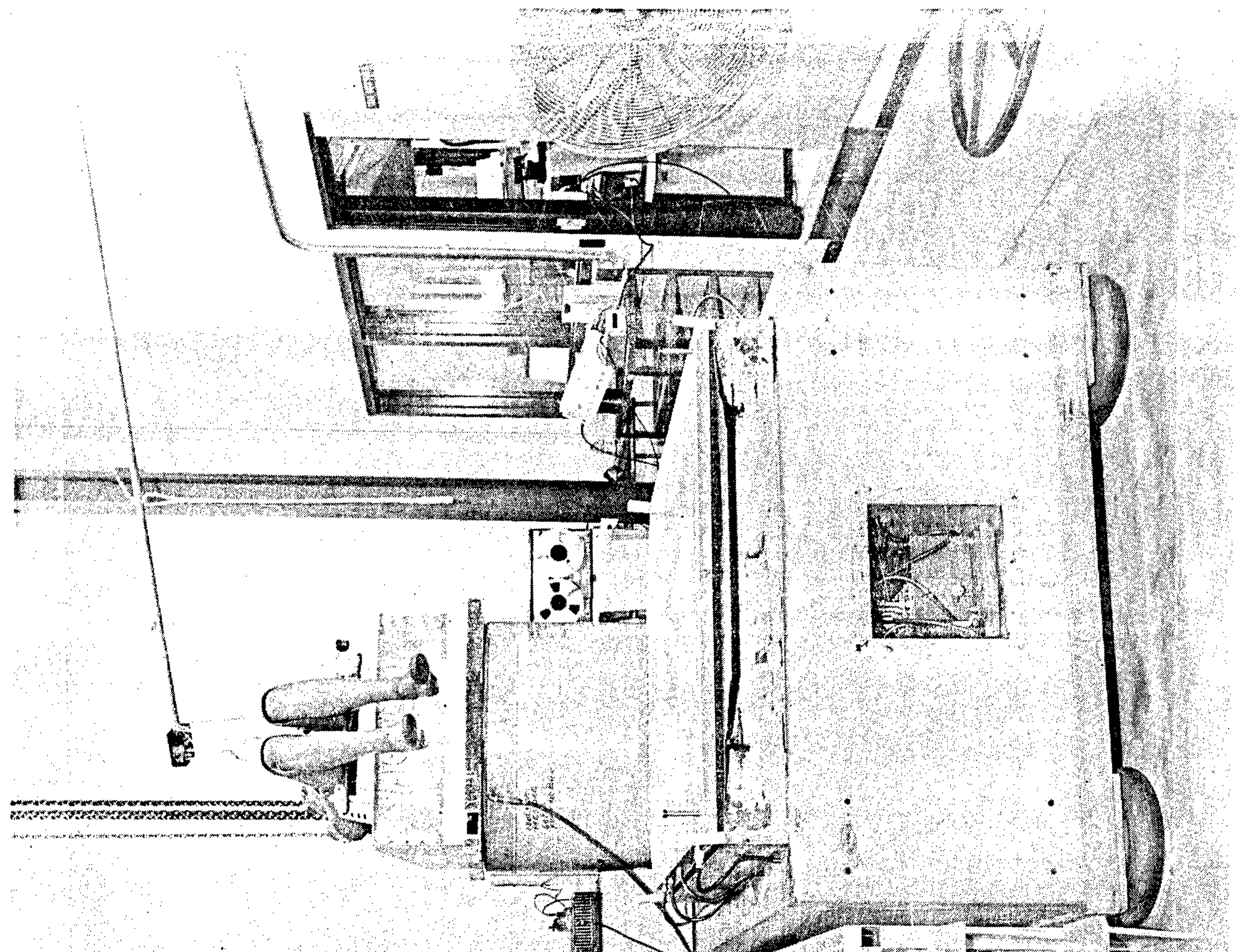
APPENDIX A

TEST SETUP PHOTOGRAPHS




LINEAR MOTION POTENTIOMETER
CONTROL ACCELEROMETER
GENERAL DYNAMICS
LAND SYSTEMS


SEAT RESPONSE ACCELEROMETER

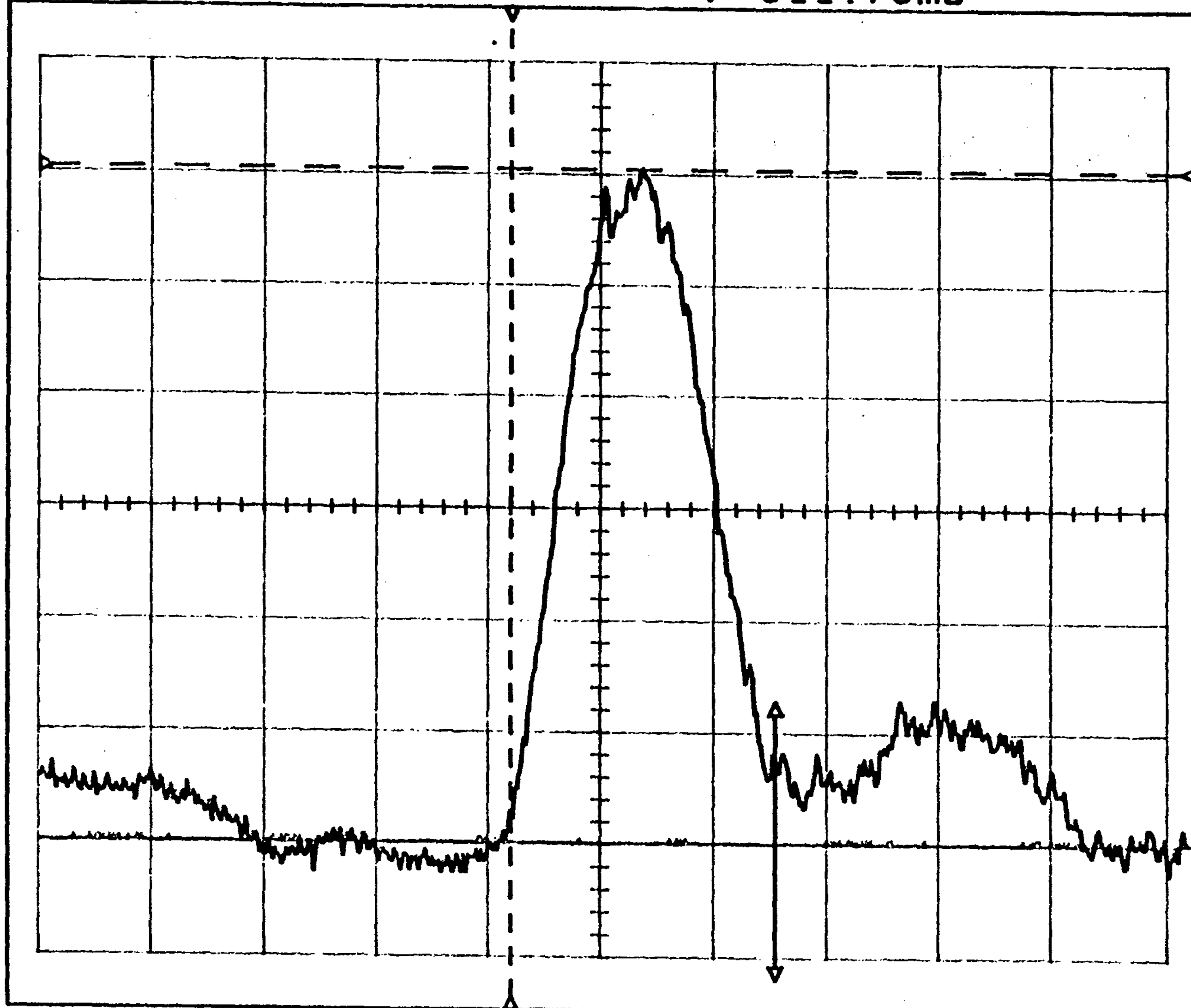


APPENDIX B

BASIC SHOCK INPUTS

Work Directive:	TW 411111	Axis +/-:	VERTICAL +	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	11.70
Serial Number:		Actual G's:	30.1	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				

REF1: -301mV : 011.70ms



DATE: Feb 14/90

TIME: 10: 41: 04

CH1: 050mV : 5ms

REF1: 050mV : 5ms

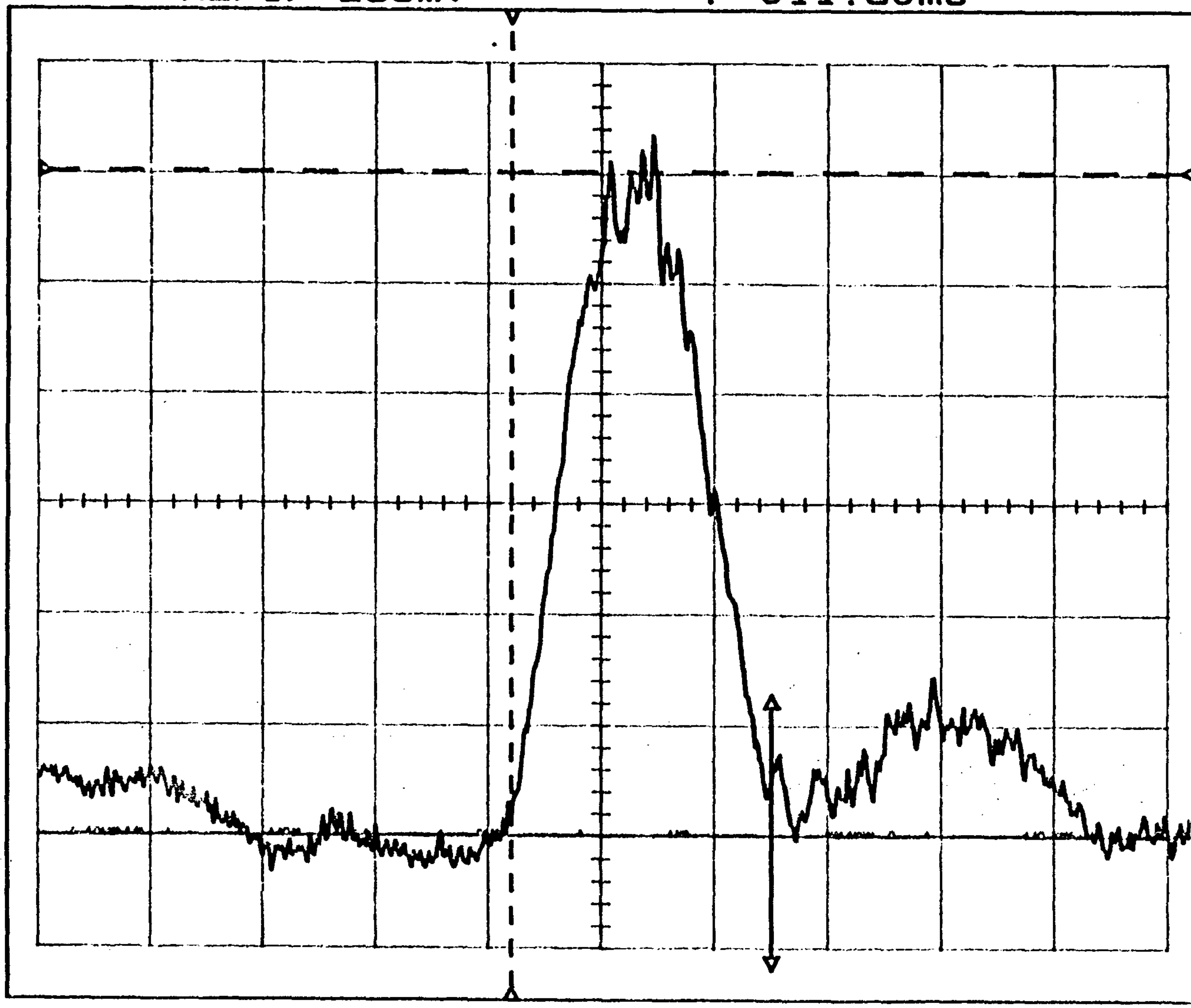
Comments: DROP 1
TEST #1
STORED RESPONSE #3

Signature: G. Doran

Insert this way

Work Directive:	TW 411111	Axis +/-:	VERTICAL +	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	11.50
Serial Number:		Actual G's:	29.9	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				

REF1: -299mV : 011.50ms



DATE: Feb 14/90

TIME: 11: 07: 38

CH1: 050mV : 5ms

REF1: 050mV : 5ms

Comments: Drop 2

Signature: Y Dora

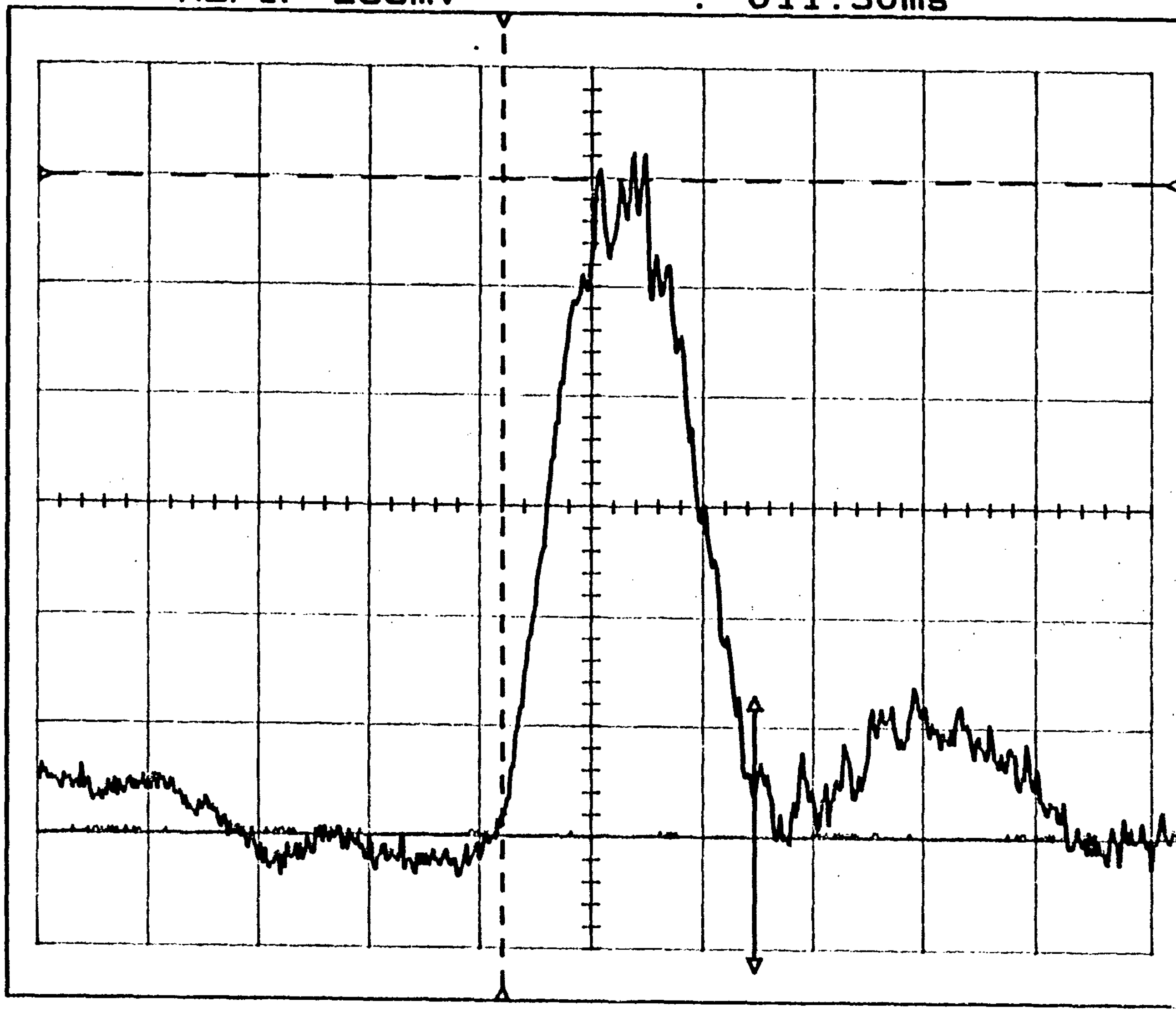
Insert this way

Work Directive: TW4/////
Test Name: COMPOSITE SEAT
Part Number:
Serial Number:
Exposure Type: BASIC SHOCK

Axis +/-: VERTICAL +
G's Div Scale: 5
Specification G's: 30 ± 3
Actual G's: 29.8

ms/Div Scale: 5
Specification ms: 11 ± 1.1
Actual ms: 11.30
Filter Setting: 2K

REF1: -298mV : 011.30ms



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CH1: 050mV : 5ms

REF1: 050mV : 5ms

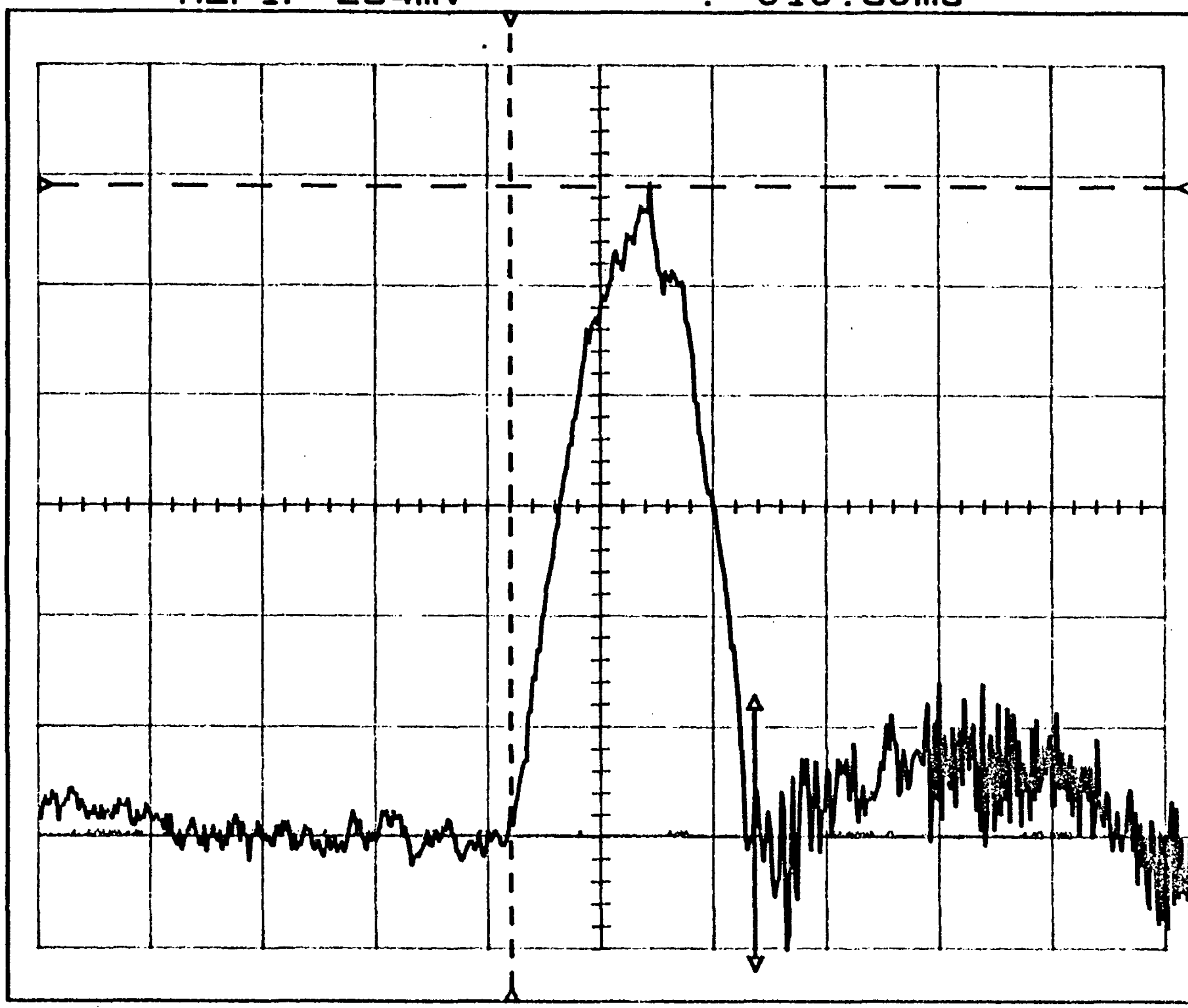
Comments: Drop 3

Signature: B. Doran

Insert this way

Work Directive:	TW 411111	Axis +/-:	VERTICAL −	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	10.80
Serial Number:		Actual G's:	29.4	Filter Setting:	5K
Exposure Type:	BASIC SHOCK				

REF1: −294mV : 010.80ms



DATE: Feb 14/90

TIME: 11: 32: 15

CH1: 050mV : 5ms

REF1: 050mV : 5ms

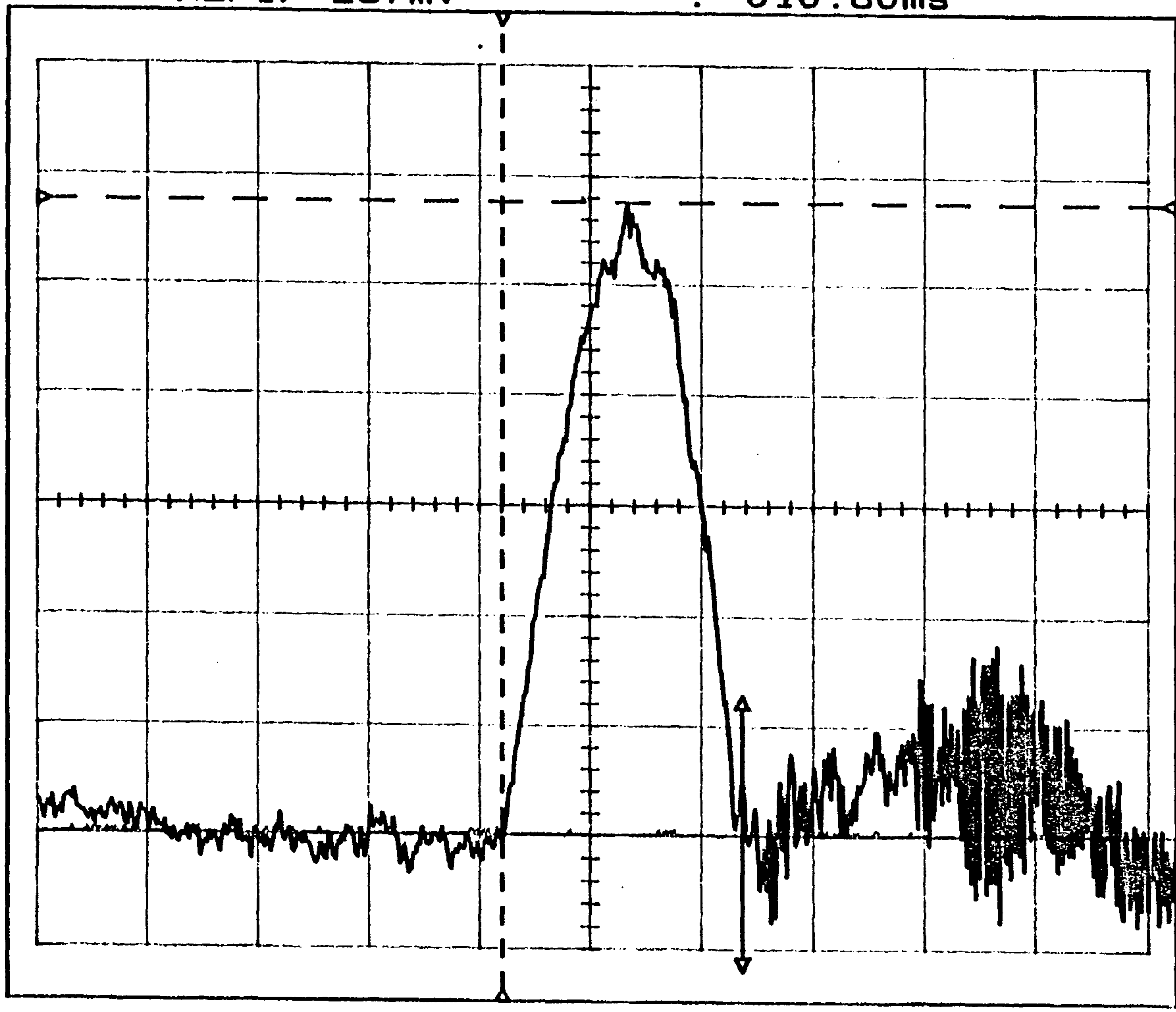
Comments: Drop 1

Signature: D. Doran

Insert this way

Work Directive:	TW41111	Axis +/-:	VERTICAL -	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	10.80
Serial Number:		Actual G's:	28.7	Filter Setting:	5K
Exposure Type:	BASIC SHOCK				

REF1: -287mV : 010.80ms



DATE: Feb 14/90

TIME: 11: 37: 18

CH1: 050mV : 5ms

REF1: 050mV : 5ms

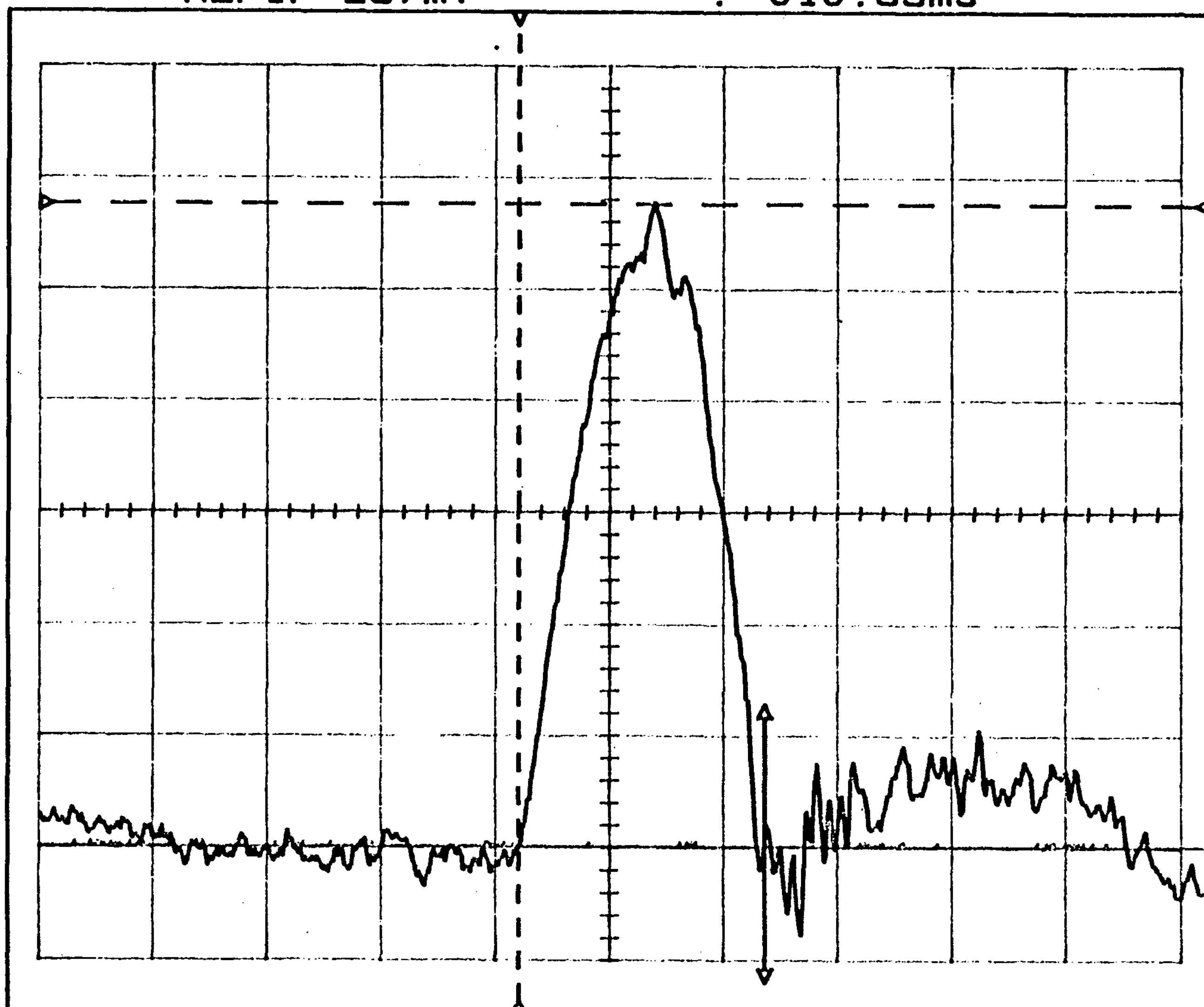
Comments: Drop 2

Signature: G. Dora

Insert this way

Work Directive:	TW4 11111	Axis +/-:	VERTICAL −	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	10.85
Serial Number:		Actual G's:	28.7	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				

REF1: -287mV : 010.85ms



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TIME: 11: 41: 32

CH1: 050mV : 5ms

REF1: 050mV : 5ms

Comments: Drop 3

Signature: G. Dan

Insert this way

Work Directive: TW 411111

Test Name: COMPOSITE SEAT

Part Number:

Serial Number:

Exposure Type: BASIC SHOCK

Axis +/-: LONGITUDINAL +

G's Div Scale: 5

Specification G's: 30 ± 3

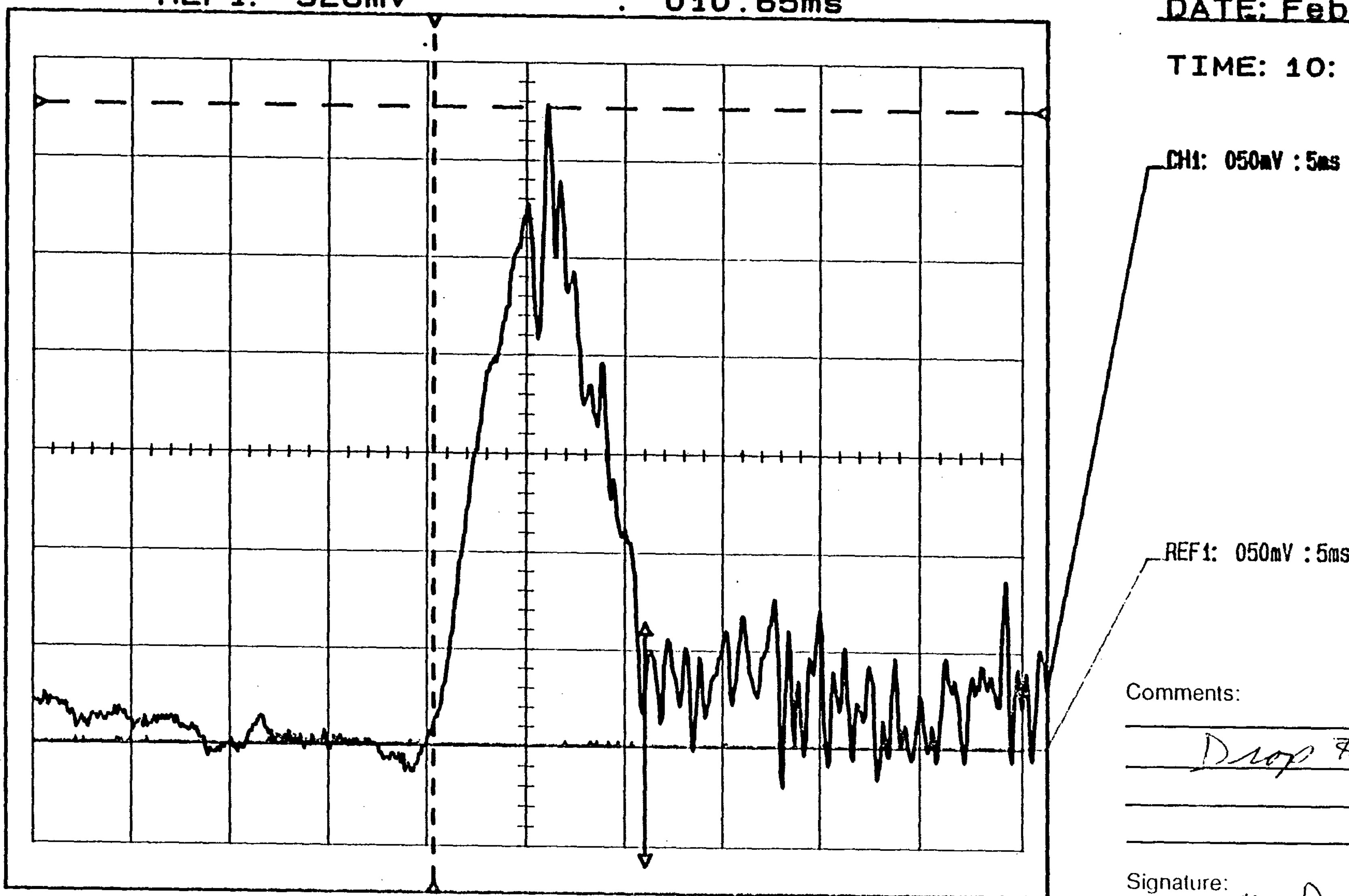
Actual G's: 32.6

ms/Div Scale: 5

Specification ms: 11 ± 1.1

Actual ms: 10.65

Filter Setting: 2K



DATE: Feb 16/90

TIME: 10: 43: 11

Comments: Drop #1

Signature: D. Don

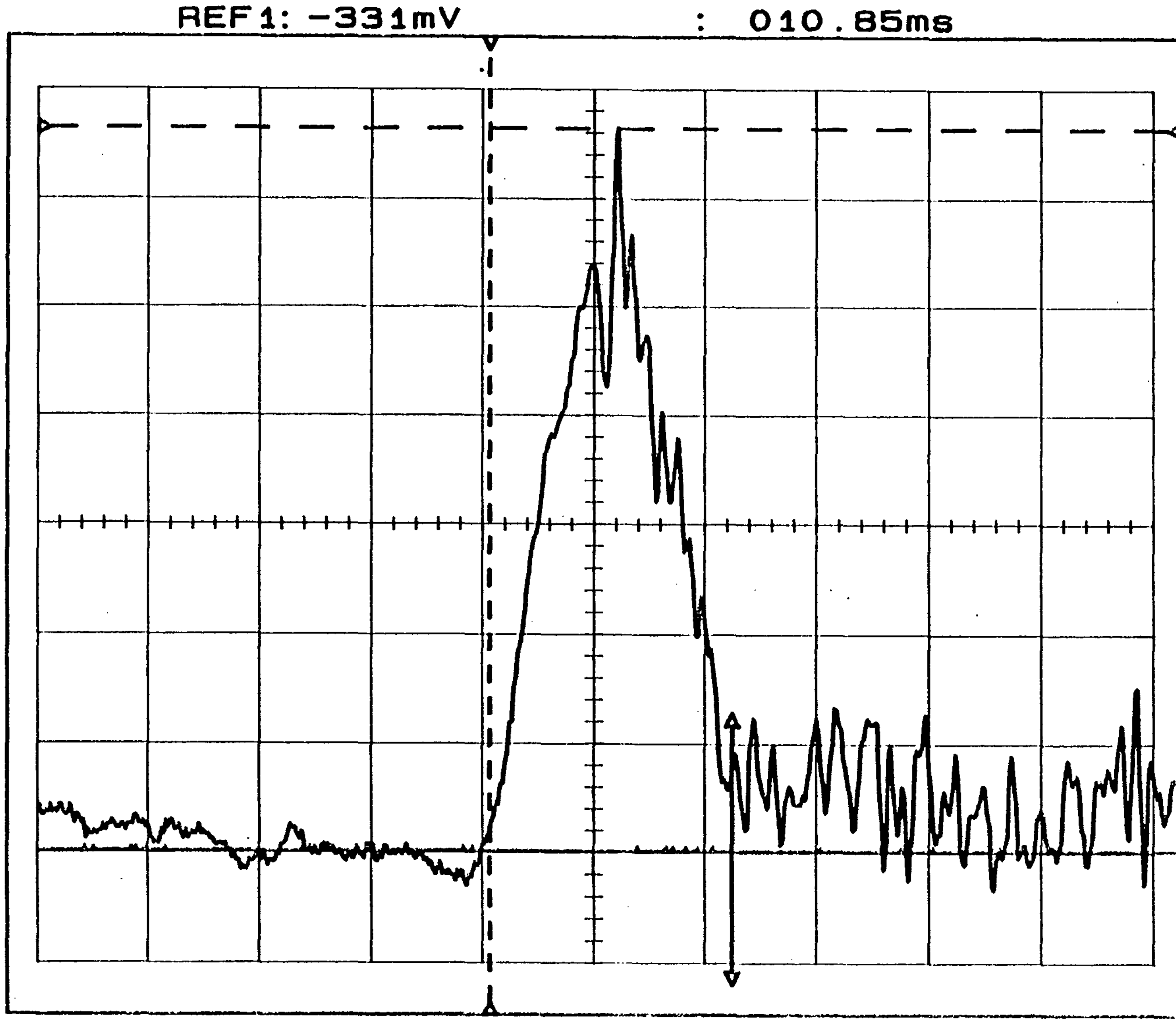
Insert this way

A-24

Work Directive: TW411111
Test Name: COMPOSITE SEAT
Part Number:
Serial Number:
Exposure Type: BASIC SHOCK

Axis +/-: LONGITUDINAL +
G's Div Scale: 5
Specification G's: 30 ± 3
Actual G's: 33.1

ms/Div Scale: 5
Specification ms: 11 ± 1.1
Actual ms: 10.85
Filter Setting: 2K



DATE: Feb 16/90

TIME: 10: 48: 25

Comments: Drop # 2

Signature: G. Dora

Insert this way

Work Directive: TW411111

Test Name: COMPOSITE SEAT

Part Number:

Serial Number:

Exposure Type: BASIC SHOCK

Axis +/-: LONGITUDINAL +

G's Div Scale: 5

Specification G's: 30 ± 3

Actual G's: 32.4

ms/Div Scale: 5

Specification ms: 11 ± 1.1

Actual ms: 10.90

Filter Setting: 2K

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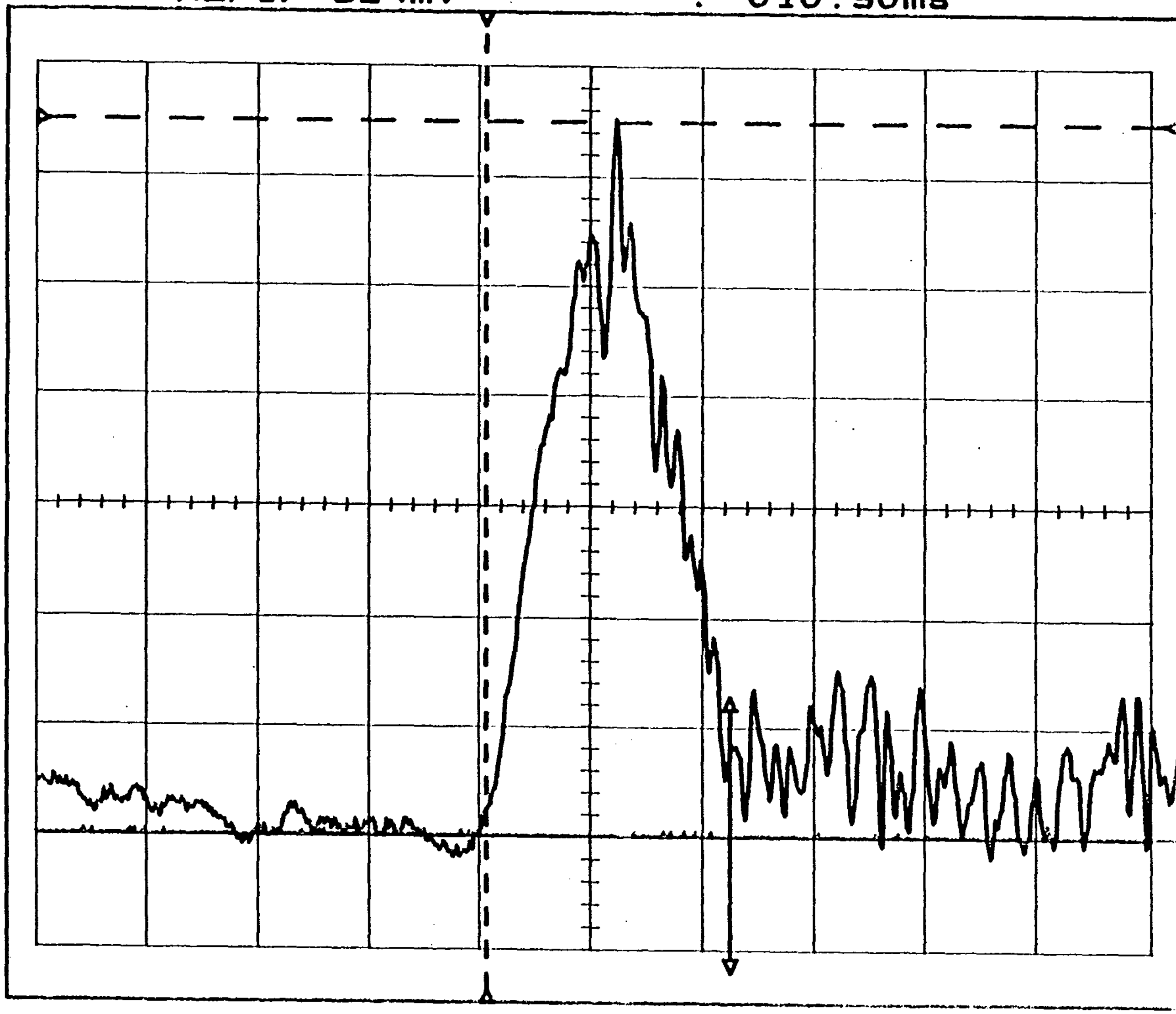
TIME: 10: 56: 28



CH1: 050mV : 5ms

REF1: 050mV : 5ms

Comments: Drop #3

Signature: G Doran

Insert this way

A-26

Part Number:

Serial Number:

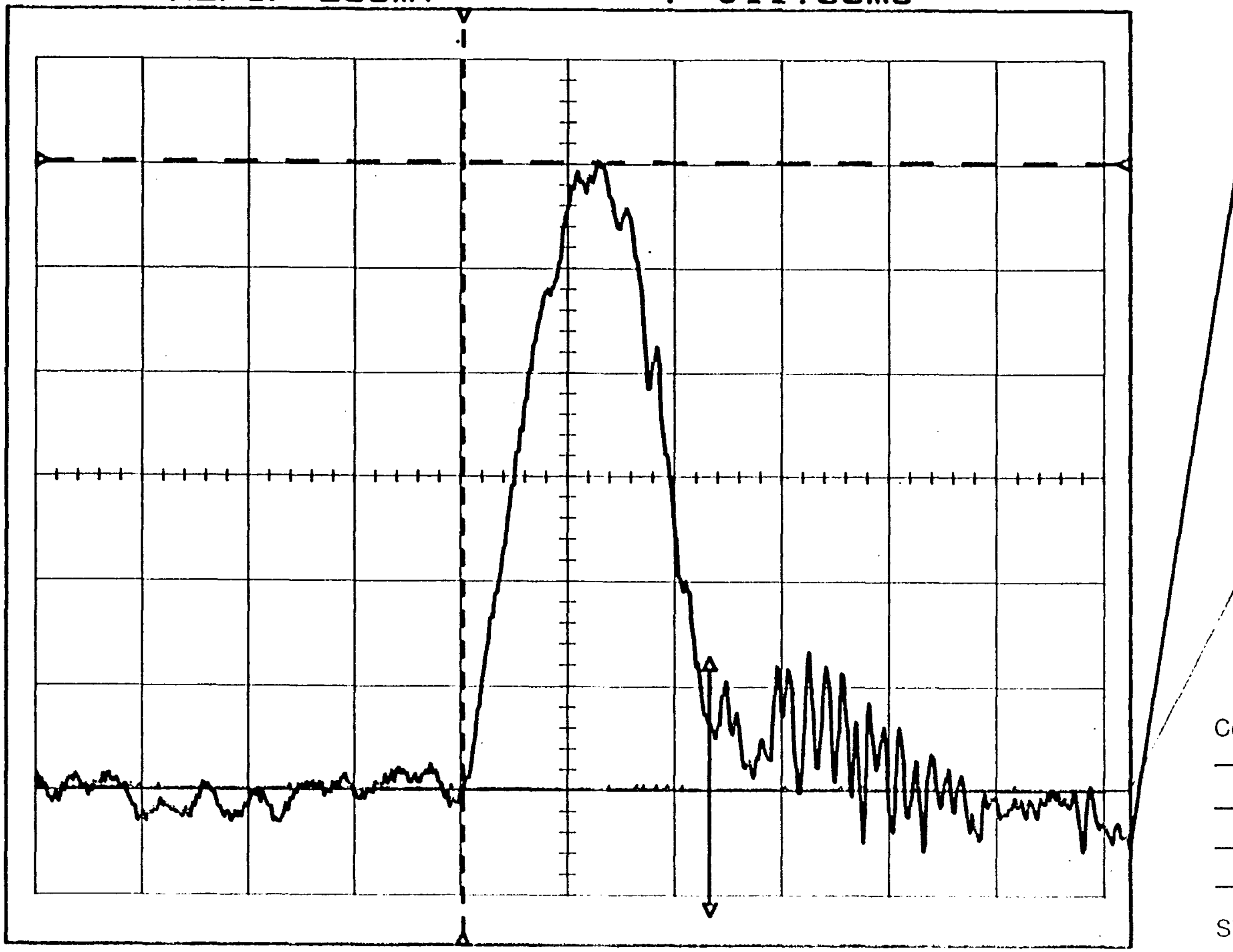
Exposure Type: BASIC SHOCK

Specification G's:

Actual G's: 27.9

Actual ms:

Filter Setting: 2K



DATE: Feb 16/90

TIME: 10: 13: 56

Comments: Drop # 2

Signature:

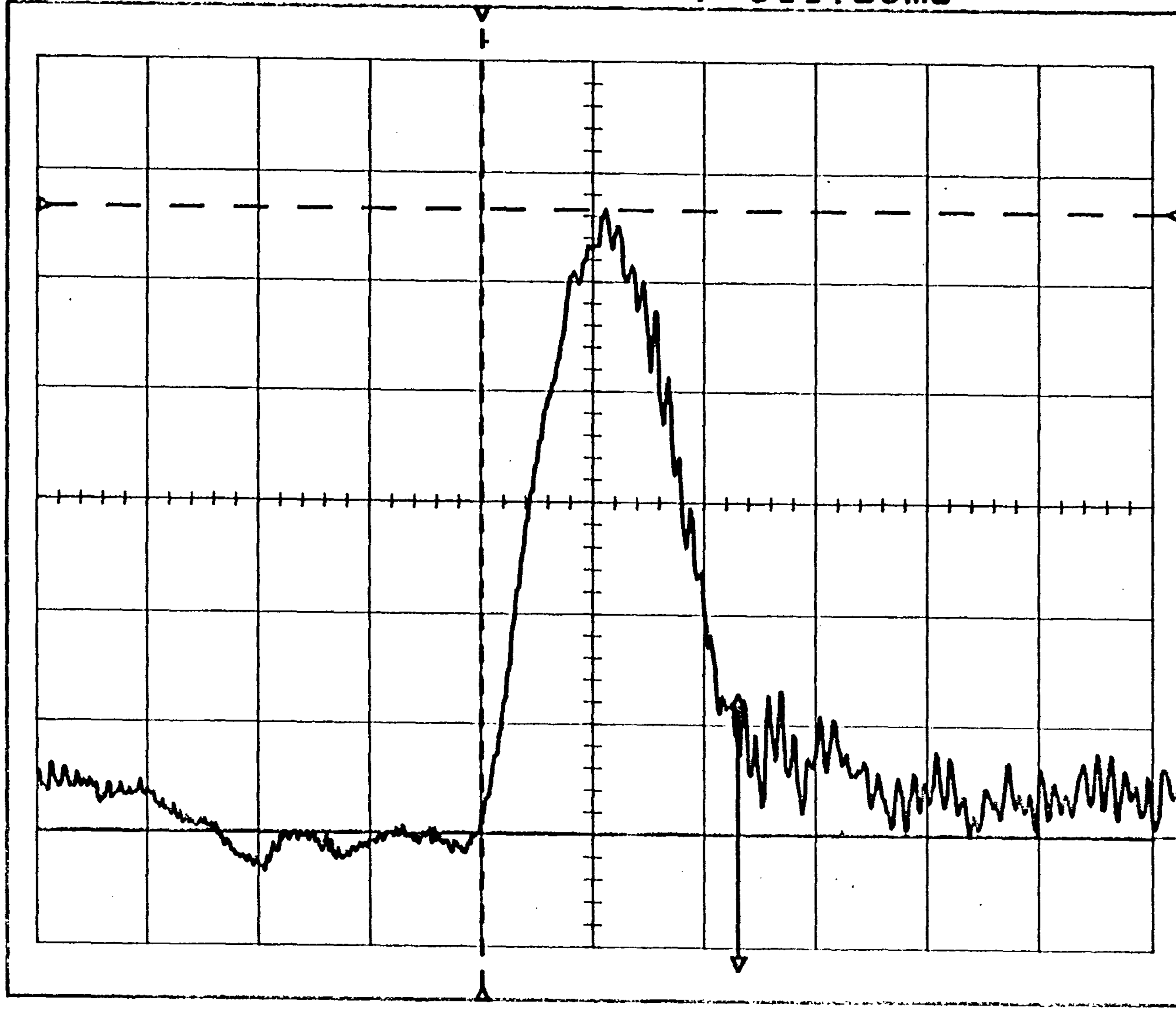
Signature:

Insert this way

A-27

Work Directive:	TW411111	Axis +/-:	LATERAL +	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11±1.1
Part Number:		Specification G's:	30±3	Actual ms:	11.50
Serial Number:		Actual G's:	28.2	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				

REF1: -282mV : 011.50ms



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TIME: 14: 38: 43

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REF1: 050mV : 5ms

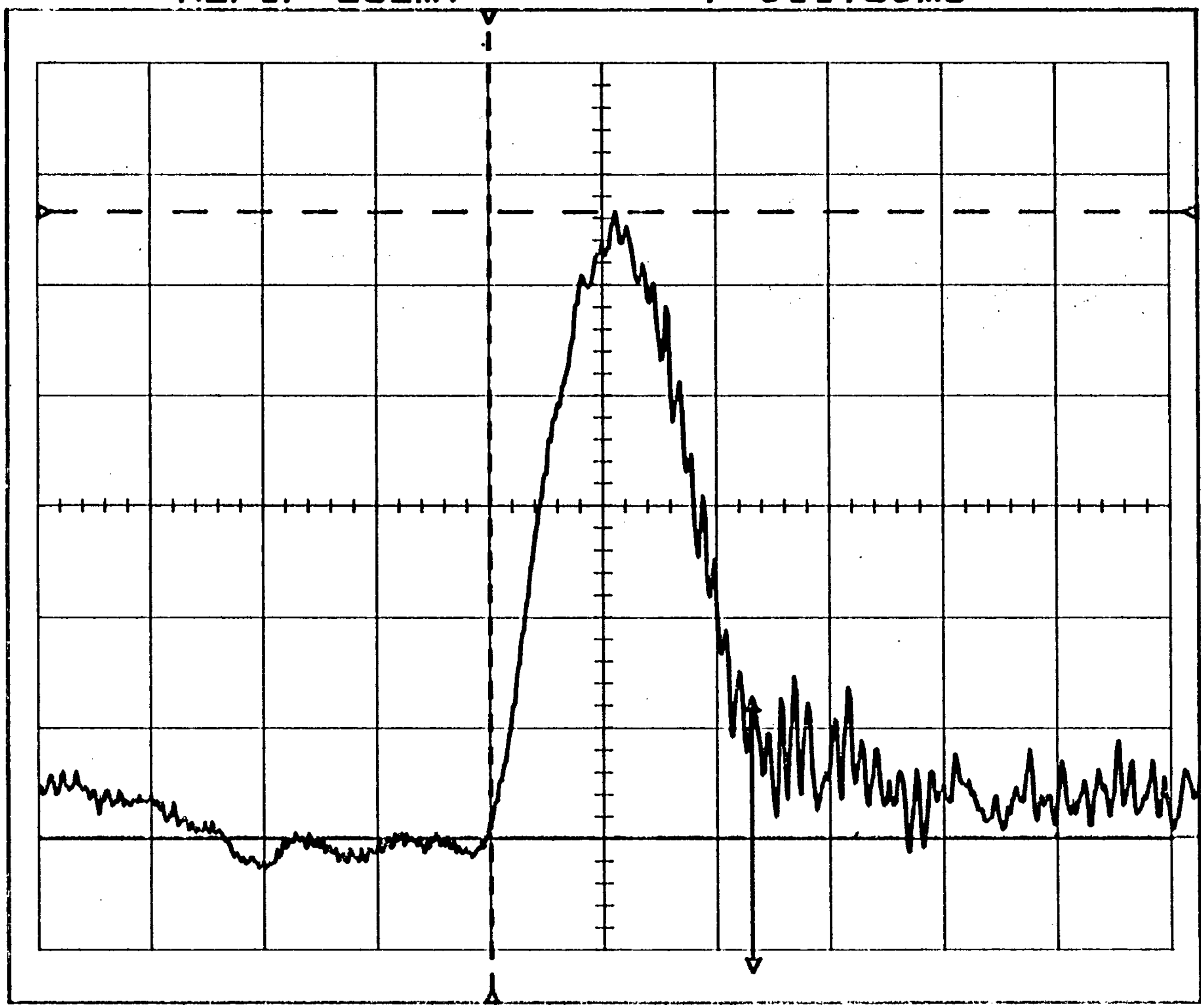
Comments: Drop #1

Signature: G. Dora

Insert this way

Work Directive:	TW 411111	Axis +/-:	LATERAL +	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	11.50
Serial Number:		Actual G's:	28.2	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				

REF1: -282mV : 011.50ms



DATE: Feb 16/90

TIME: 14: 43: 34

CH1: 050mV : 5ms

REF1: 050mV : 5ms

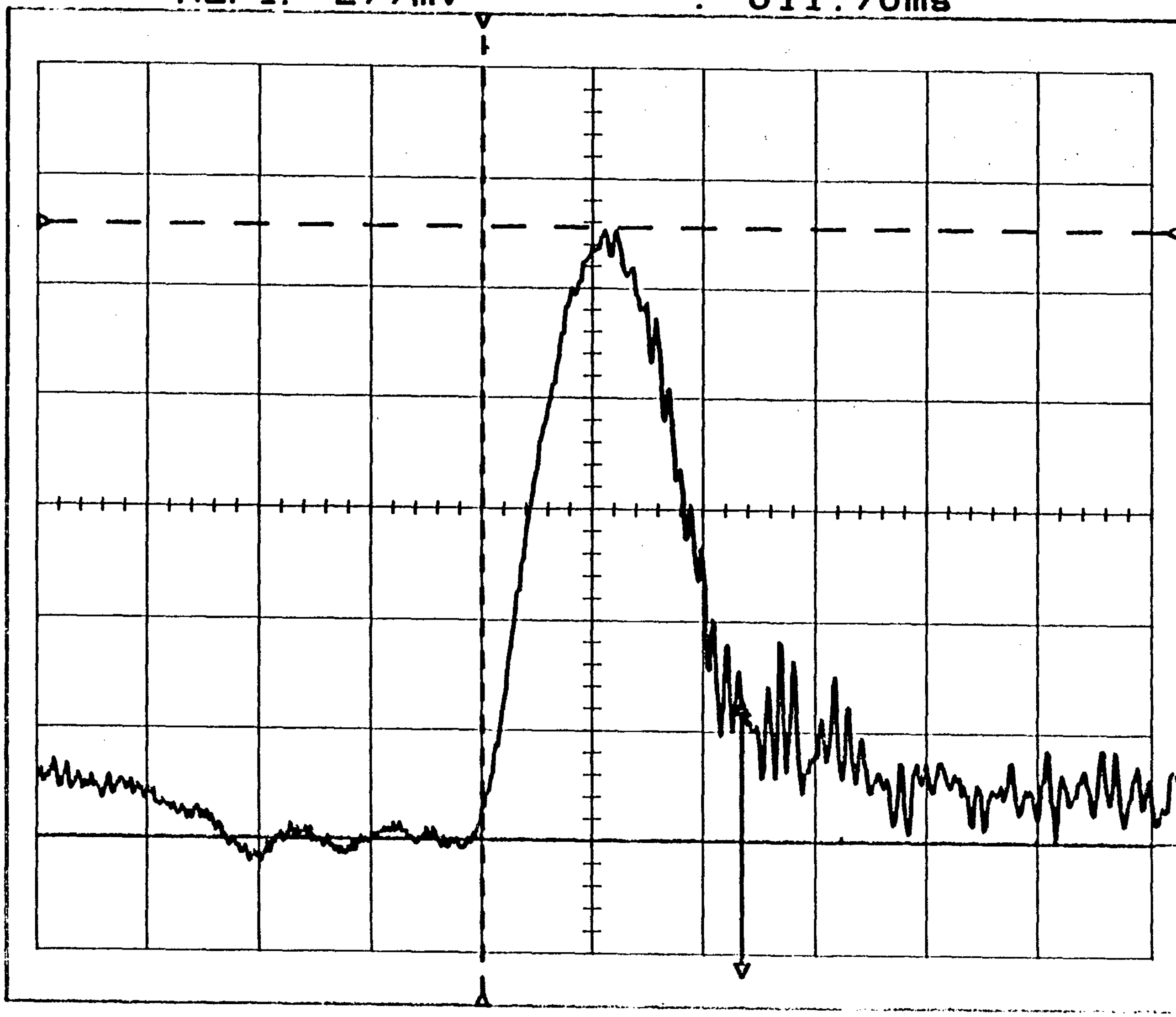
Comments:

Drop #2

Signature: [illegible signature]

Insert this way

Work Directive:	TW 411111	Axis +/-:	LATERAL +	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	11.70
Serial Number:		Actual G's:	27.7	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				



DATE: Feb 16/90

TIME: 14: 48: 15

CH1: 050mV : 5ms

REF1: 050mV : 5ms

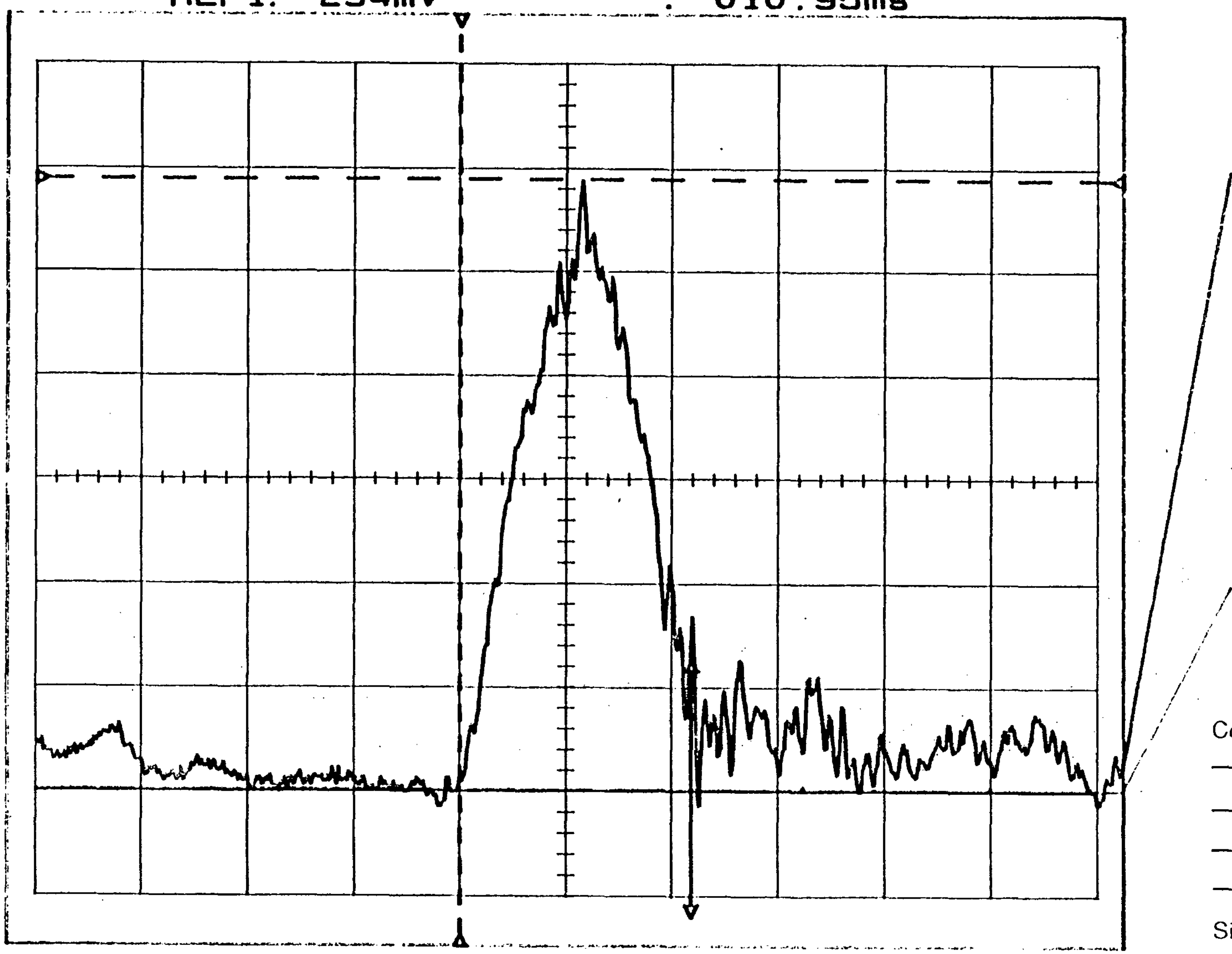
Comments:

Damp #3

Signature: G. Dore

Insert this way

Work Directive:	TW 411111	Axis +/-:	LATERAL -	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	10.95
Serial Number:		Actual G's:	29.4	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				



DATE: Feb 16/90

TIME: 14: 59: 51

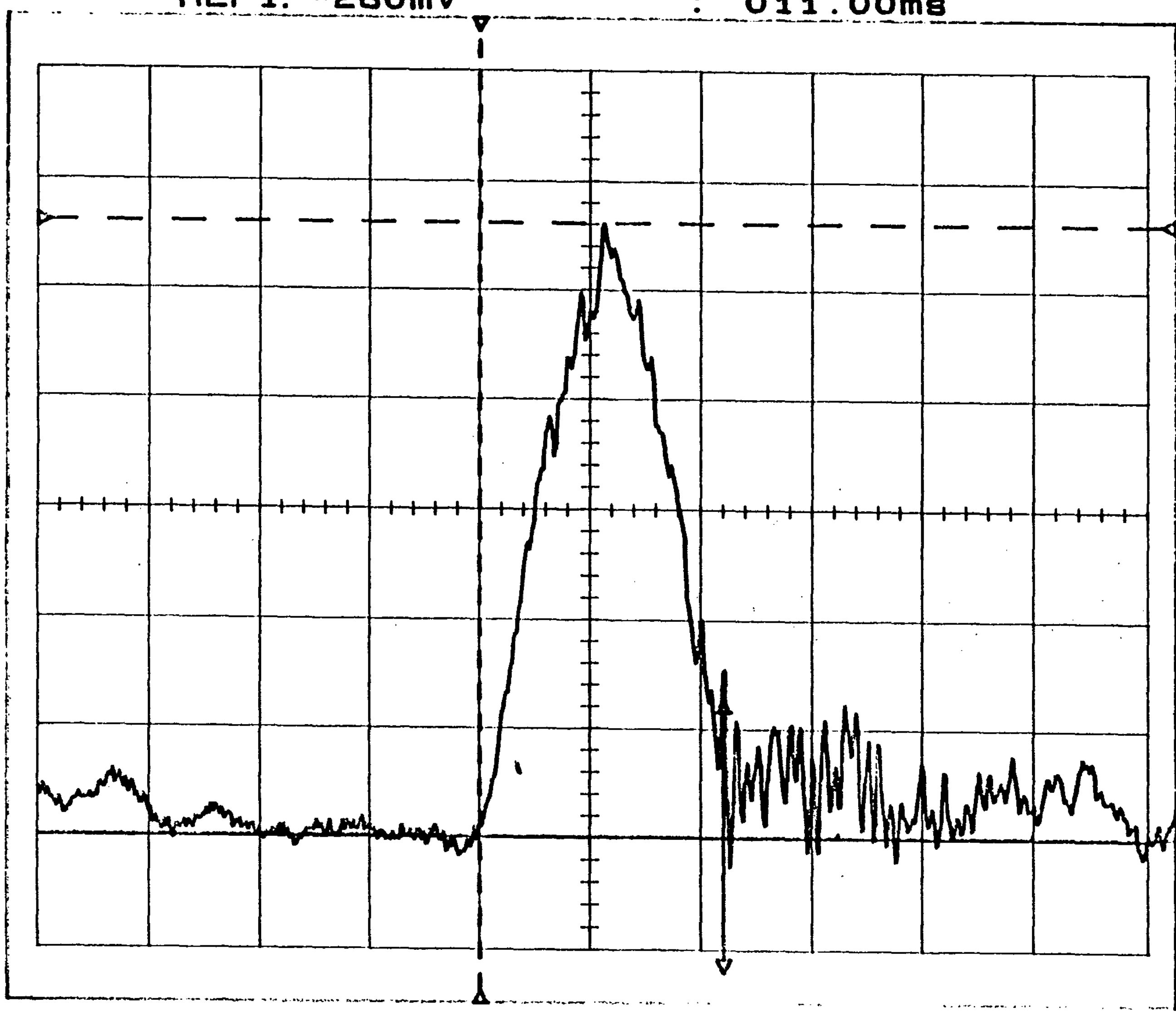
Comments: Drop #1

Signature:

Insert this way

A-31

Work Directive:	TW 411111	Axis +/-:	LATERAL -	ms/Div Scale:	5
Test Name:	COMPOSITE SEAT	G's Div Scale:	5	Specification ms:	11 ± 1.1
Part Number:		Specification G's:	30 ± 3	Actual ms:	11.00
Serial Number:		Actual G's:	28.0	Filter Setting:	2K
Exposure Type:	BASIC SHOCK				



DATE: Feb 16/90

TIME: 15: 05: 11

Comments: Drop # 2

Signature: G. Doran

Insert this way

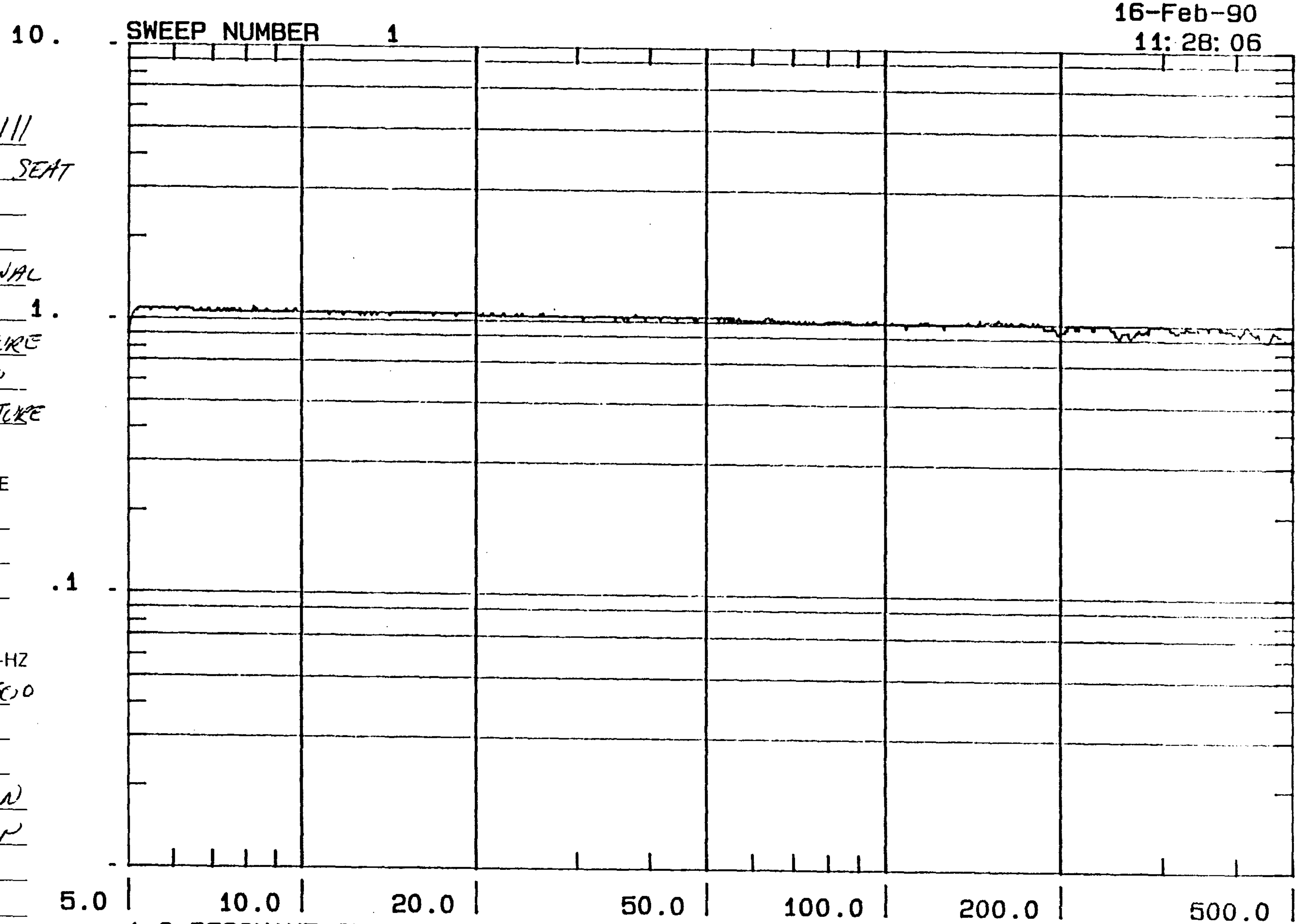
APPENDIX C

DRIVER'S SEAT VIBRATION RESPONSE PLOTS

Insert this end first

COMPOSITE SEAT TEST

16-Feb-90
11: 28: 06



Work Directive TW411111
Test Item COMPOSITE SEAT
Part No.
Serial No.
Input Axis LONGITUDINAL
Control S/N AAF14
Location TOP FIXTURE
Response S/N 1040
Location TOP FIXTURE

Resonant Dwells:

G	HZ	TIME

A-34

Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments:
DUMMY

Signature G. Daren

1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 2
STORED RECORD 34

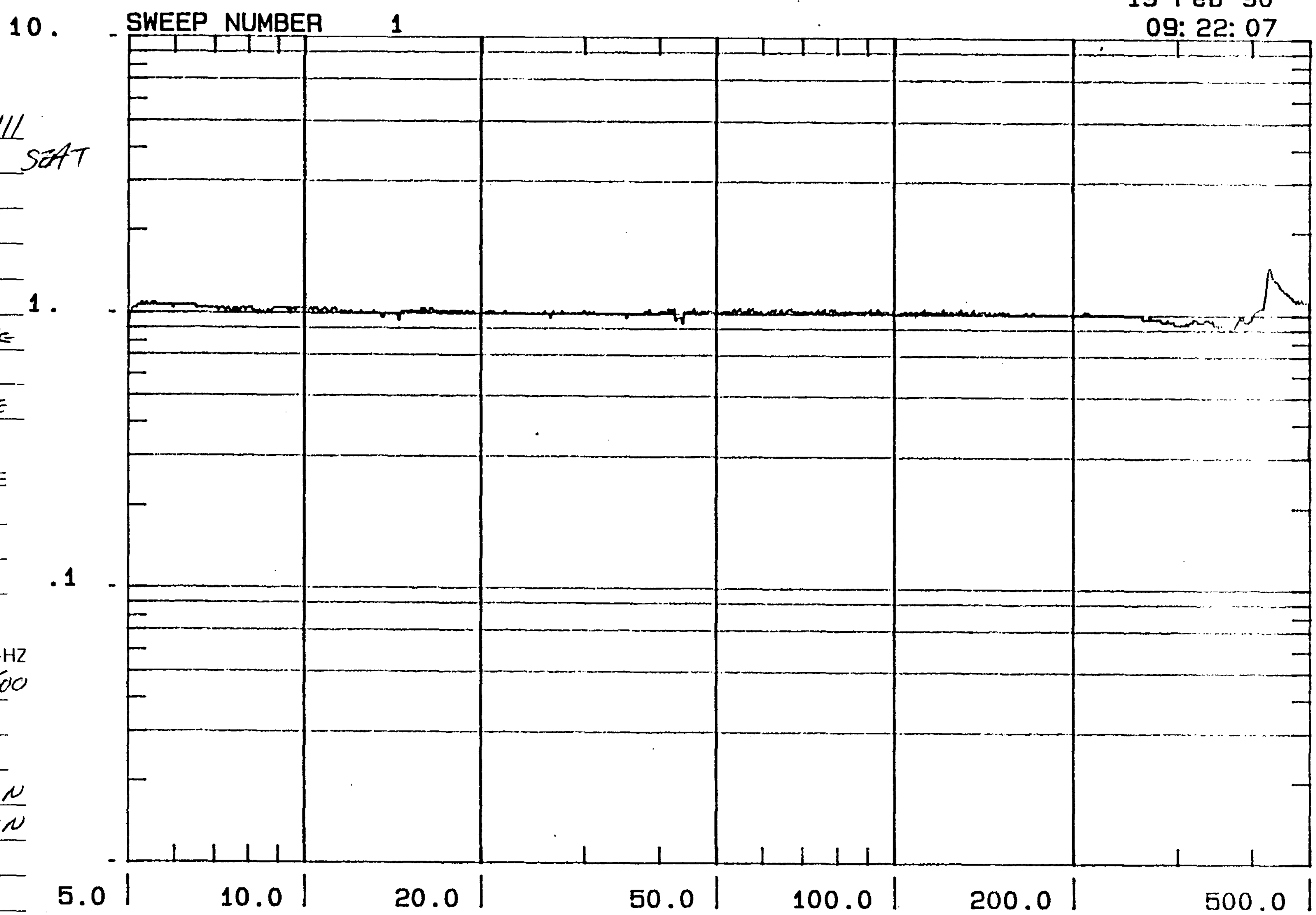
UNIT # 3 TEST #30

DURATION : 00: 07: 30

Insert this end first

COMPOSITE SEAT TEST

19-Feb-90
09: 22: 07



1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 2
STORED RECORD 11

UNIT # 3 TEST #31

DURATION : 00: 07: 30

Work Directive TW 411111
Test Item COMPOSITE SEAT
Part No. ________
Serial No. ________
Input Axis LATERAL
Control S/N AAF14
Location TOP FIXTURE
Response S/N 1040
Location FIXTURE

Resonant Dwells:

G	HZ	TIME

A-35

Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments:
NO DUMMY

Signature G. Doran

Insert this end first

COMPOSITE SEAT TEST

SWEEP NUMBER 1

14-Feb-90
14: 24: 37

G

Work Directive TW411111
Test Item COMPOSITE SEAT
Part No. ____
Serial No. ____
Input Axis VERTICAL
Control S/N AHF14
Location FIXTURE
Response S/N 1048
Location SEAT

Resonant Dwells:

G	HZ	TIME

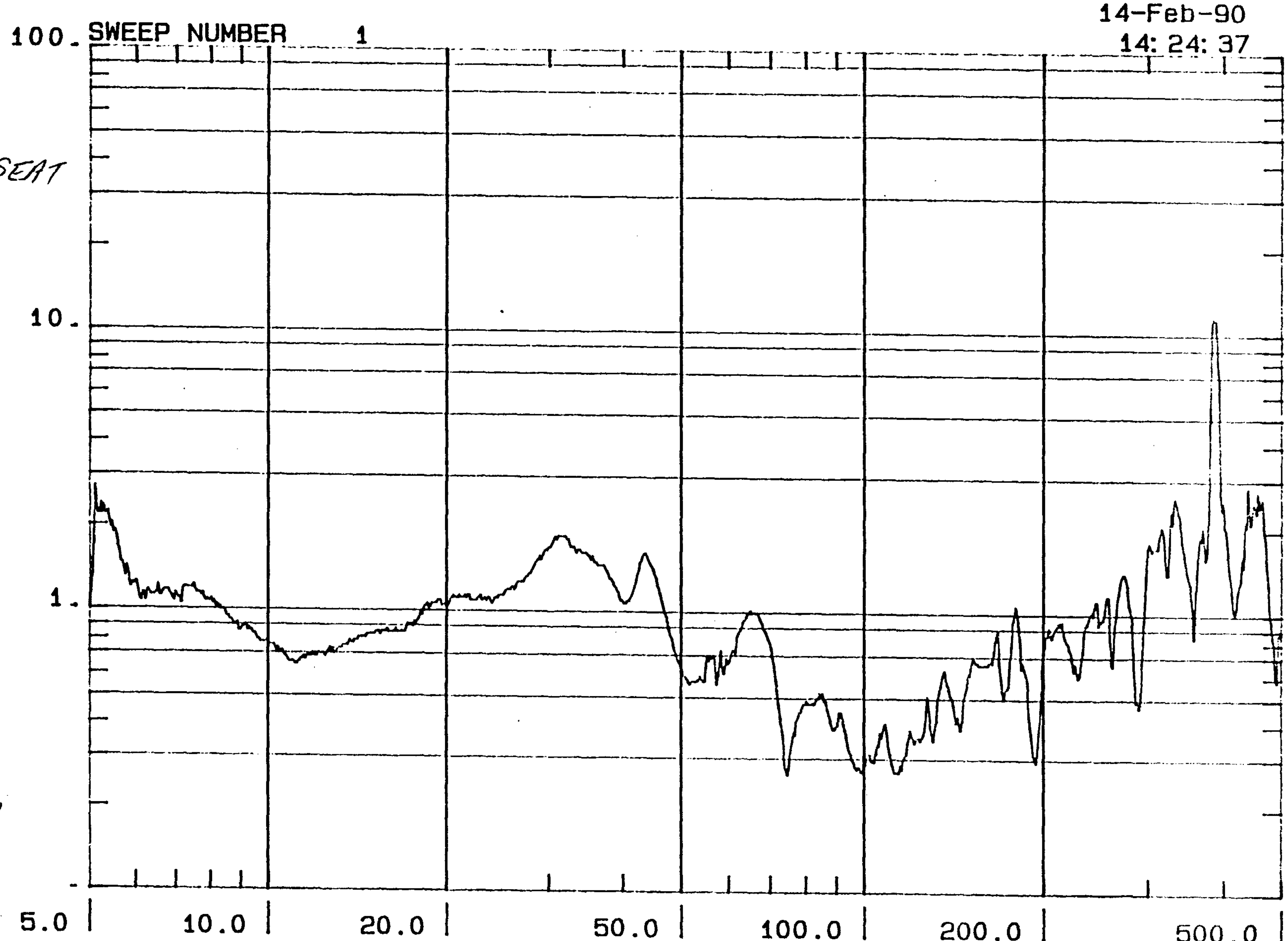
Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments: WITH DUMMY

Signature G. Doran

A-36



1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 2
STORED RECORD 6

UNIT # 3 TEST #30

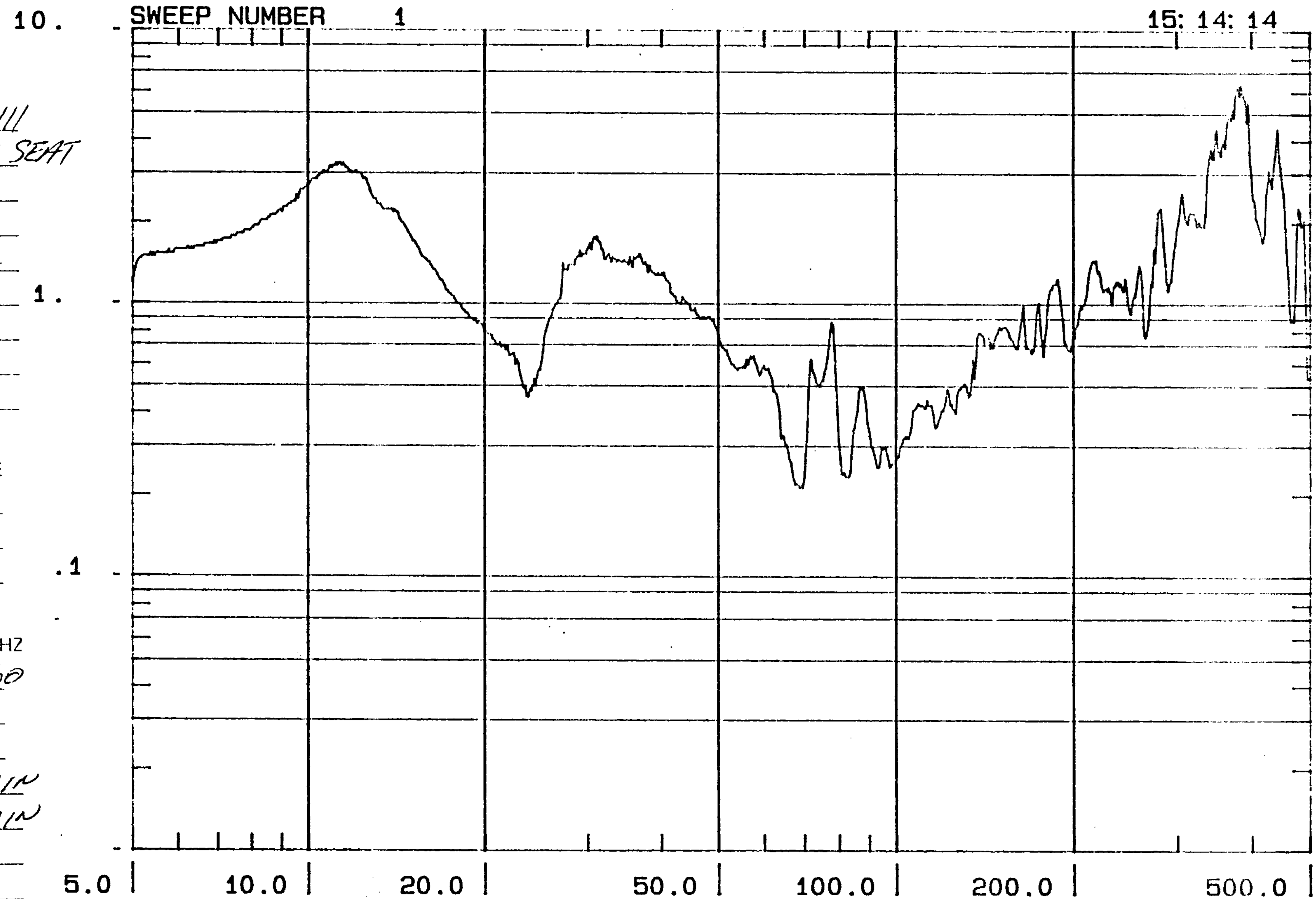
DURATION : 00: 07: 30

Insert tr
end firs

COMPOSITE SEAT TEST

SWEEP NUMBER 1

14-Feb-90
15: 14: 14



1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 2
STORED RECORD 12

UNIT # 3 TEST #30

DURATION :

LOG FREQ

00: 07: 30

Work Directive TW411111
Test Item COMPOSITE SEAT
Part No.
Serial No.
Input Axis VERTICAL
Control S/N AAF14
Location FIXTURE
Response S/N 1048
Location SEAT

Resonant Dwells:

G	HZ	TIME

Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments: NO
DUMMY

Signature B. Dora

A-37

Insert the end first

COMPOSITE SEAT TEST

16-Feb-90
11: 28: 14

SWEEP NUMBER 1

G

Work Directive TW 411111
Test Item COMPOSITE SEAT
Part No.
Serial No.
Input Axis LONGITUDINAL
Control S/N AAF14
Location TOP FIXTURE
Response S/N 1048
Location SEAT

ıant Dwells:

i	HZ	TIME

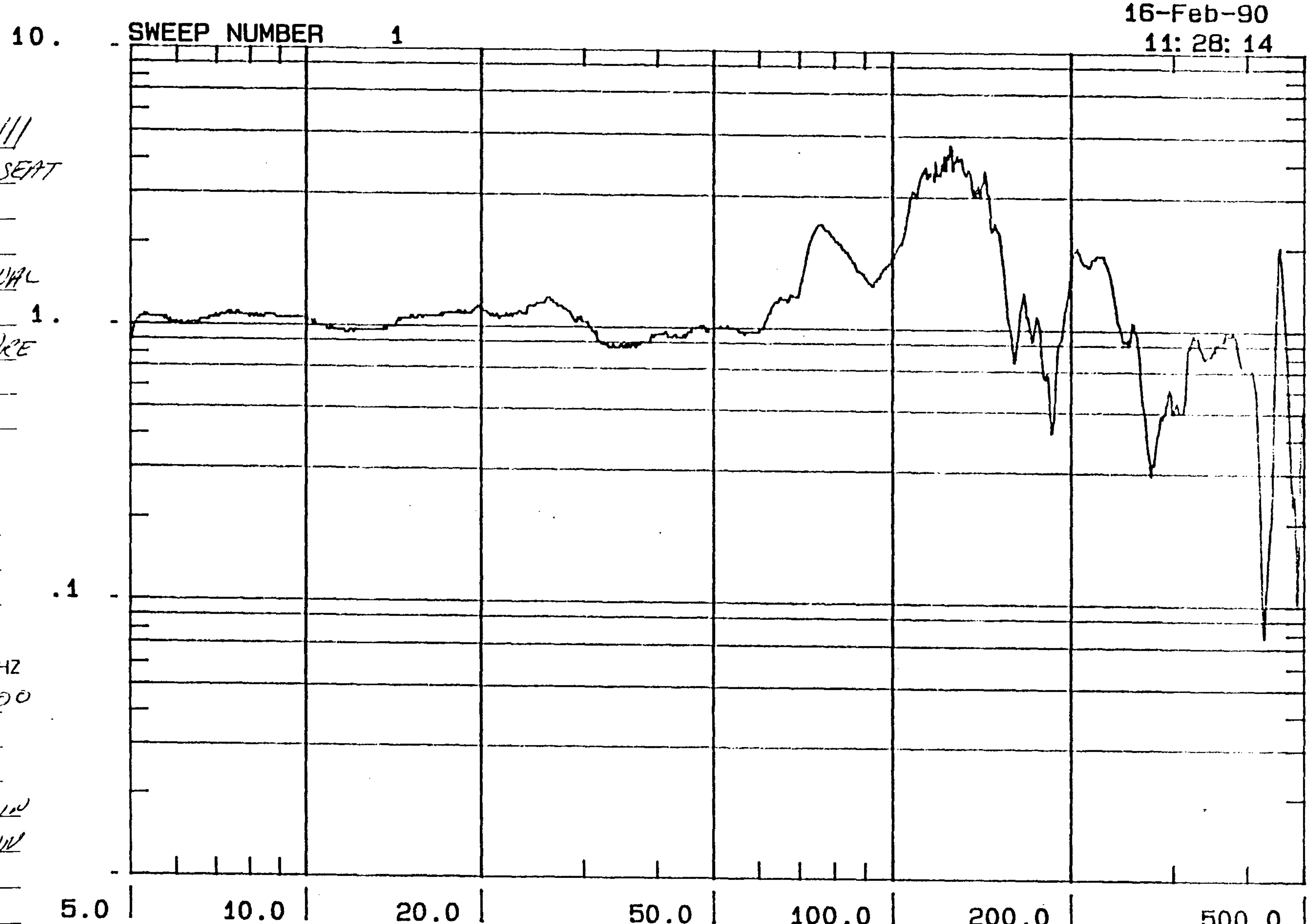
Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments:
DUMMY

Signature G. Don

A-38



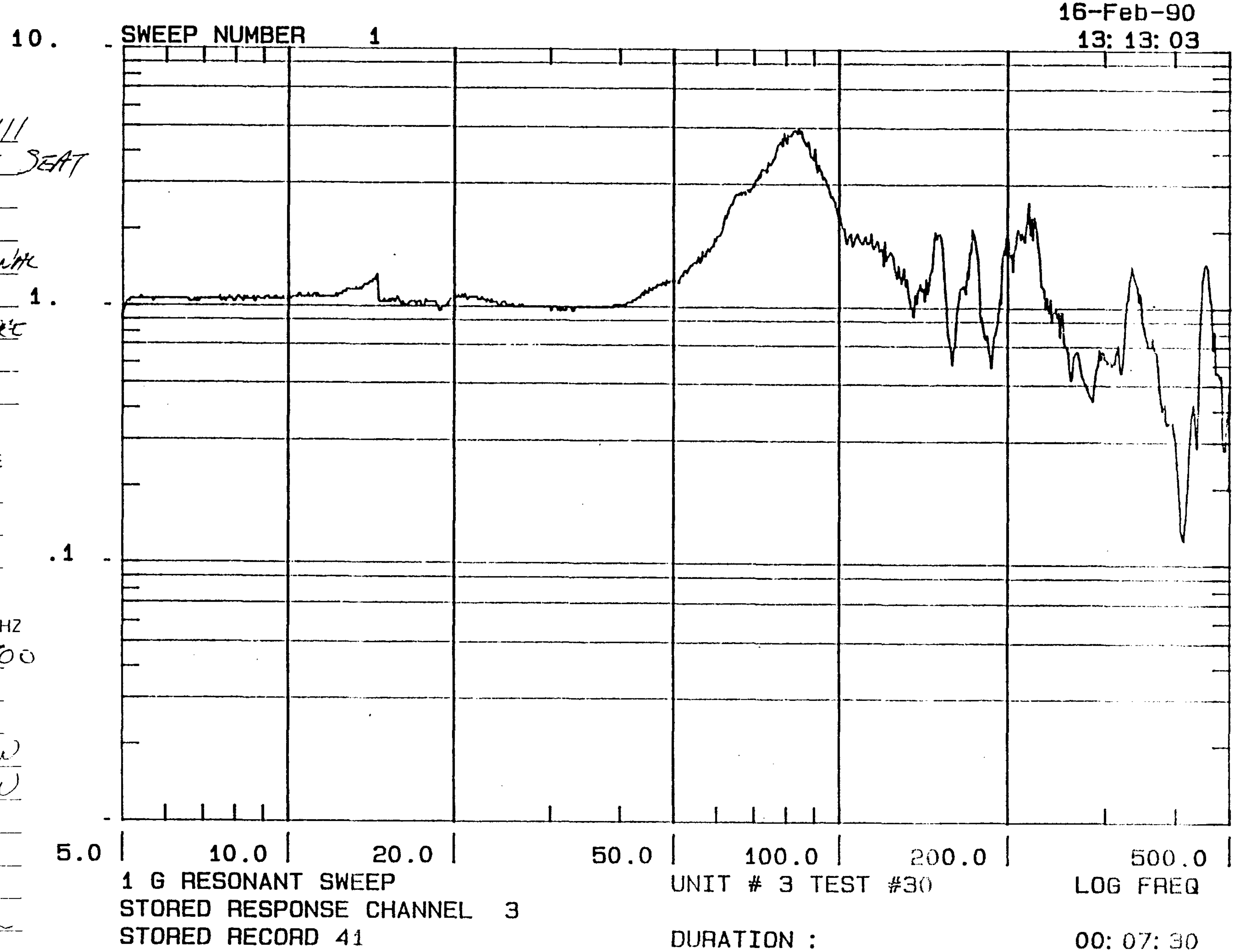
1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 3
STORED RECORD 35

UNIT # 3 TEST #30

DURATION : 00: 07: 30

Insert t· end firs·

COMPOSITE SEAT TEST



Work Directive TW411111

Test Item COMPOSITE SEAT

Part No. ______

Serial No. ______

Input Axis LONGITUDINAL

Control S/N AAF14

Location TOP FIXTURE

Response S/N 1048

Location SEAT

R----nant Dwells:

HZ	TIME

Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN

Total Time 15 MIN

Comments:

No Dummy

Signature G. Dora

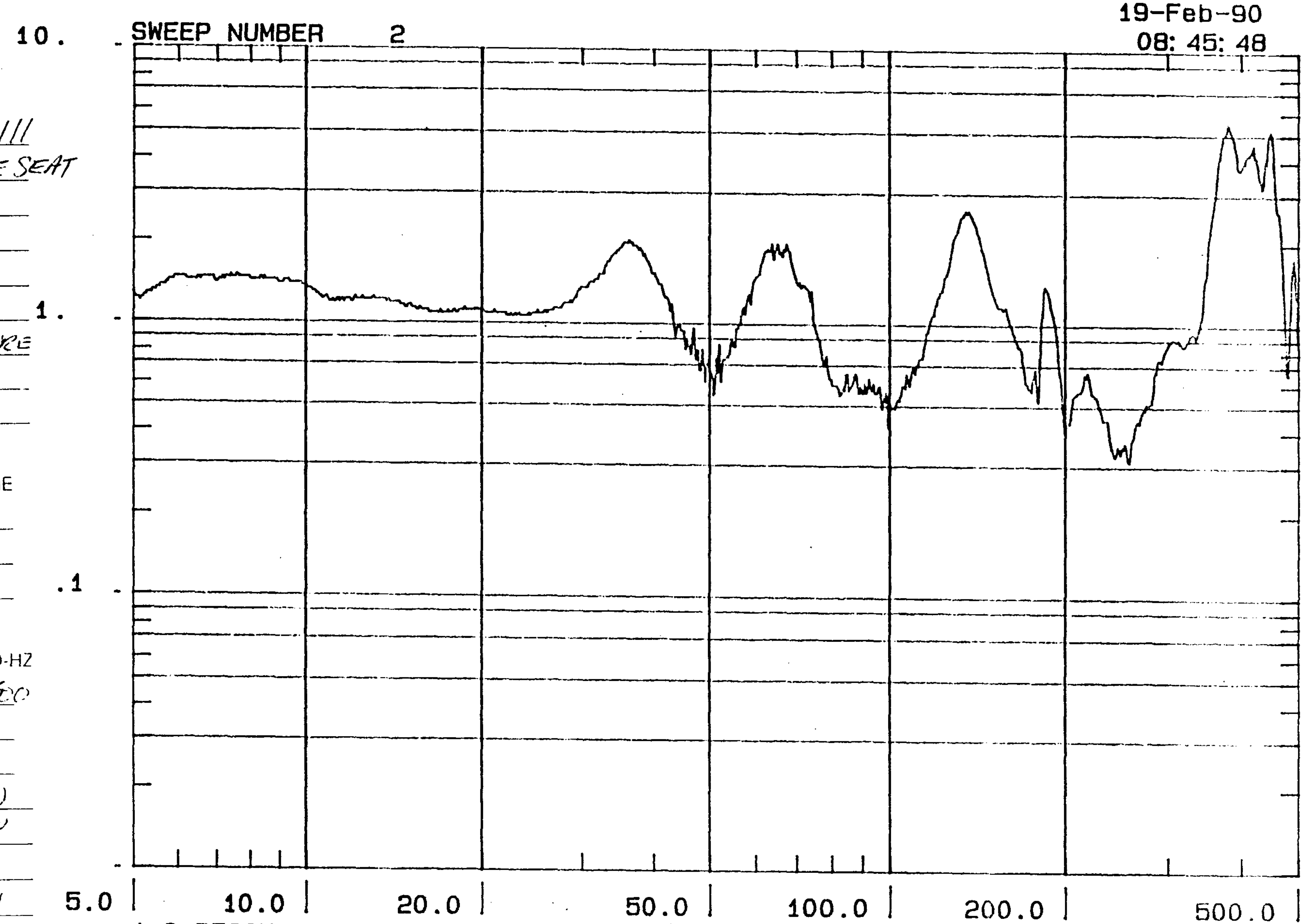
A-39

Insert this end first

COMPOSITE SEAT TEST

SWEEP NUMBER 2

19-Feb-90
08: 45: 48



1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 3
STORED RECORD 9

UNIT # 3 TEST #31

DURATION : 00: 07: 30

Work Directive Tic'411111
Test Item COMPOSITE SEAT
Part No. ______
Serial No. ______
Input Axis LATERAL
Control S/N AAF14
Location TOP FIXTURE
Response S/N 1048
Location SEAT

ant Dwells:

HZ	TIME

A-40

Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments: WITH DUMMY

Signature H. Dow

Insert this end first

COMPOSITE SEAT TEST

SWEEP NUMBER 2

19-Feb-90
09: 29: 29

G

Work Directive TW 411111
Test Item COMPOSITE SEAT
Part No. ____
Serial No. ____
Input Axis LATERAL
Control S/N AAF14
Location TOP FIXTURE
Response S/N 1048
Location SEAT

Resonant Dwells:

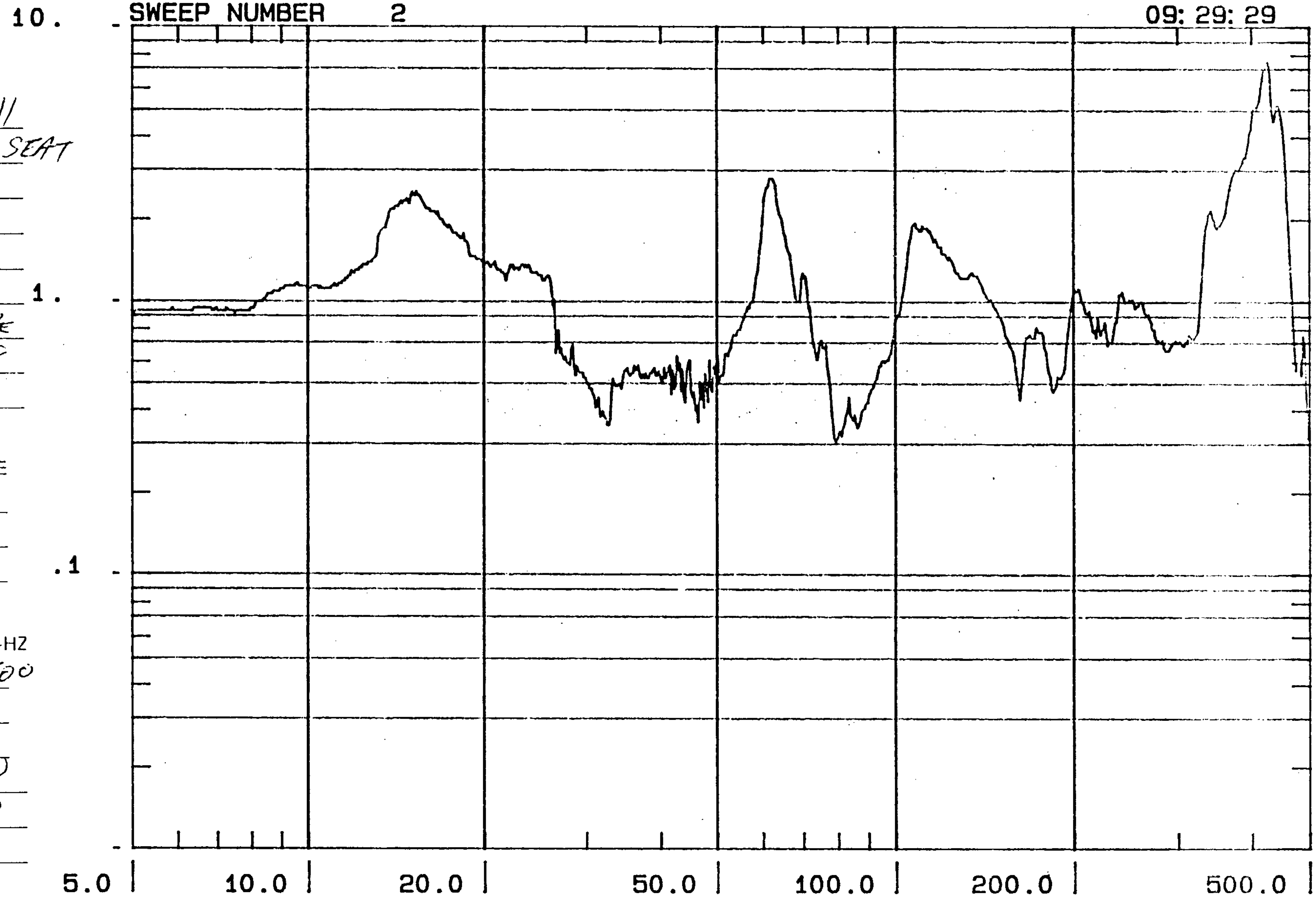
G	HZ	TIME

Frequency Cycling:

G	D.A.	BAND-HZ
±1		5-500

Sweeptime 7.5 MIN
Total Time 15 MIN
Comments: No DUMMY

Signature [signature]



1 G RESONANT SWEEP
STORED RESPONSE CHANNEL 3
STORED RECORD 15

UNIT # 3 TEST #31

LOG FREQ

DURATION : 00: 07: 30

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GENERAL DYNAMICS
Land Systems Division
P.O. Box 2074, Warren, Michigan 48090-2074

JHT/90-314

17 December 1990

Mr. Wyman E. Young, AMSTA-IRDB
Department of the Army
U.S. Army Tank Automotive Command
Warren, Michigan 48397-5000

Dear Mr. Young:

Subject: DAAE07-89-C-R041, M1A1 Composite Driver's Seat Scientific and Technical Report - Final

Reference: DI-S-4057, Sequence A002
Document Number TW-89-04057-001A

General Dynamics Land Systems Inc. is transmitting by way of DD250 two copies of the subject final report to AMSRA-TMC. Additional copies have been submitted to the agencies identified on the distribution list (18).

Should you have any questions, please contact the undersigned at (313) 825-7035 or the above address.

Sincerely,

GENERAL DYNAMICS LAND SYSTEMS INC.

for
J. H. Theisen
Senior Contract Representative

RSMT

AMSTA-TMC (1/1 via DD250)